THE
ASTROPHYSICAL JOURNAL
AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME XXXV MAY 1912 NUMBER 4

SLIT-WIDTH CORRECTIONS IN SPECTRO-PHOTOMETRY AND A NEW FORM OF VARIABLE SECTORED DISK

By EDWARD P. HYDE

PART I. SLIT-WIDTH CORRECTIONS IN SPECTRO-PHOTOMETRY

A. INTRODUCTION

The spectro-photometer, in its various forms, has been widely employed as a precise instrument in studying relative energy distributions within the limits of the visible spectrum. As formerly used, except in the case of polarization instruments, the settings on the spectro-photometer were made by varying the width of one of the collimator slits. Later the errors which attend this practice, even when the Vierordt double slit is employed, were studied,[1] and this study led to the more general use of the rotating sectored disk in one or another form. But although the spectro-photometer has been widely employed as a precise instrument, only quite recently has any attention been paid to the errors which enter on account of the impurity of the spectrum due to the finite slit-widths of the telescope and of the two collimators. The corresponding error in the measurement of energy distribution by the use of the infra-red spectrometer and linear bolometer or thermopile was evaluated

[1] Capps, *Astrophysical Journal*, **11**, 25, 1900.

by Runge[1] some years ago. The neglect of this error in spectro-photometric measurements may have arisen from the conception that the error would be small because the measurements are relative—the energy distribution of one spectrum being measured in terms of that of another somewhat similar spectrum. This fact does in general reduce the magnitude of the error, but on the other hand in spectro-photometric comparisons the sensibility-curve of the eye enters to produce an added complication.

In connection with an investigation by the author[2] and others of the radiating properties of metals, spectro-photometric measurements were used in determining the relative energy distributions in the spectra of two sources. The question arose as to the possible errors incident to the assumption that the ordinates of the observed luminosity-curves of two continuous spectra, as of a black body at two different temperatures, bear the same ratios to one another throughout the visible spectrum as the ordinates of the corresponding pure energy-curves. A theoretical investigation of the problem was begun, but before its completion the same question was discussed by Nichols and Merritt[3] in connection with their work on phosphorescence. Inasmuch as their method of treatment, consistent with their object in view, was somewhat different from that of the present author and since this investigation led incidentally to the design of a new form of variable sectored disk, the author[4] presented a brief report of his work to the Physical Society. For similar reasons it seems expedient to publish a more detailed account of the investigation, and to describe more in detail the new form of sectored disk adapted to spectro-photometric measurements.

B. THEORY OF SLIT-WIDTH CORRECTIONS

In the following discussion it is assumed that the substitution method of measurement is employed. Thus (Fig. 1) a constant comparison source is placed before the slit S' of one collimator, and

[1] *Annalen der Physik*, **60**, 712, 1897.

[2] Hyde, Cady, and Middlekauff, *Trans. Ill. Eng. Soc.*, **4**, 334, 1909. Hyde, *Jour. of Franklin Inst.*, **169**, 439, 1910.

[3] *Physical Review*, **30**, 328, 1910.

[4] *Ibid.*, **31**, 183, 1910.

the two sources whose spectra are to be intercompared are successively placed before the slit S of the second collimator.[1] Through the slit T of the telescope the two spectra formed by the prism P are seen juxtaposed in the compound field of view of the Lummer-Brodhun contrast prism L.

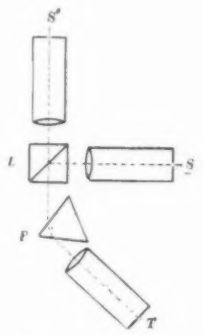


FIG. 1.—Diagrammatic sketch of spectrophotometer.

In spectro-photometric comparisons measurements of the relative *luminosities* of the *impure* spectra of two sources are made. The problem, therefore, is to determine from these measurements the relative curves of *energy* distribution in the *pure* spectra of the two sources. To this end we seek an expression of the intensity in the pure energy spectrum of a source at S (Fig. 1) in terms of the luminosity of its impure

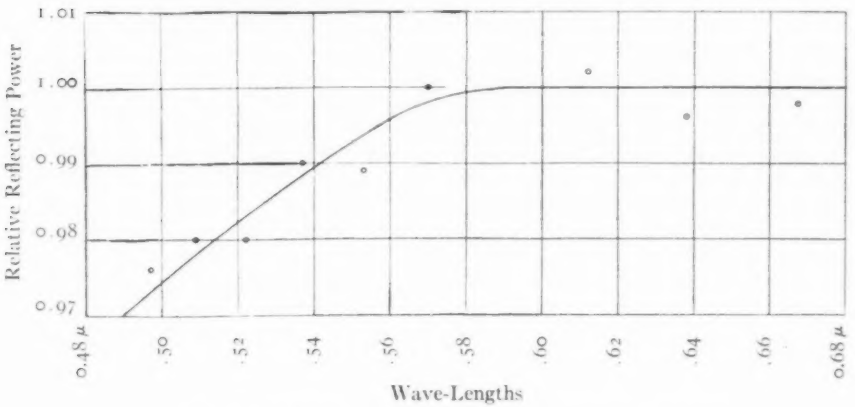


FIG. A.—Relative reflecting power of magnesium carbonate

[1] In practically all the work of the author the light from the source under investigation falls, not upon the slit directly, but upon a block of compressed magnesium carbonate which is mounted at an angle before the slit and which diffusely reflects the incident light into the collimator. In Fig. A are given the results of a study of the selective reflection of the magnesium carbonate block. It is seen that its reflection coefficient at the red end of the spectrum is about 3 per cent greater than that for blue light. If the substitution method is employed and the proper precaution is taken, there is no need to make any allowance for the selective reflection of the magnesium carbonate block.

spectrum formed by the prism P in the plane of the slit T of the telescope.

Let

a = slit-width of S measured in angular units on the divided circle of the telescope.[1]

a' = slit-width of S' measured in angular units on the divided circle of the telescope.

b = slit-width of T measured in the same angular unit.

$c = \frac{a+b}{2}$.

θ = angle of deviation of the ray considered.

$f(\theta)$ = intensity in the pure energy spectrum of a source.

$\psi(\theta)$ = sensibility of the eye for the pure spectrum.

$\phi(\theta) = \psi(\theta) f(\theta)$ = luminosity of the pure spectrum of a source.

$F(\theta)$ = luminosity of the impure spectrum of a source, represented in the present case by the luminous flux through the telescope slit, T.

We seek first to find an expression for $\phi(\theta)$ in terms of $F(\theta)$ and constants. It will then be a simple matter to determine $f(\theta)$ in terms of $F(\theta)$ if the sensibility-curve of the eye $[\psi(\theta)]$ is assumed as known. As will be shown later, however, this last step is not necessary, since in spectro-photometry relative measurements of two spectra are made, and if the substitution method is employed, and the comparison spectrum is maintained constant, the function $\psi(\theta)$ is not directly involved.

Expression of $F(\theta)$ as a function of $\phi(\theta)$.—The luminous flux through the slit T of the telescope from the source at S may be separated for theoretical considerations into two portions. The first portion corresponds to wave-lengths for which the images of S formed at the eyepiece slit T by the light of those wave-lengths fall entirely within the limits of T. The second portion consists of the remaining flux from S through T. Let v represent in magnitude a deviation $\Delta\theta$ in θ, where θ corresponds to the deviation of

[1] This slit-width thus measured will theoretically be slightly different in different regions of the spectrum owing to the magnification by the prism, which is equal to unity only at the angle of minimum deviation. If, however, the slit-widths of S are always measured in angular units on the divided circle of the telescope no error will result in the application of the following analysis.

the rays which form an image of S at the center of the slit T of the telescope. The two portions of the luminous flux through the slit T are represented by the first and second integrals, respectively, of the right-hand member of equation (1).[1]

Where $b>a$

$$F(\theta)=\left.\begin{aligned}&\int_{0}^{\frac{b-a}{2}}[\phi(\theta+v)+\phi(\theta-v)]dv+\int_{\frac{b-a}{2}}^{\frac{b+a}{2}}\frac{b+a-2v}{2a}[\phi(\theta+v)\\&\qquad\qquad+\phi(\theta-v)]dv\end{aligned}\right\}\tag{1}$$

Expanding by Taylor's theorem the functions $\phi(\theta+v)$ and $\phi(\theta-v)$ there follows—

$$F(\theta)=\left.\begin{aligned}&\int_{0}^{\frac{b-a}{2}}[2\phi(\theta)+\frac{2v^2}{2!}\phi^{II}(\theta)+\frac{2v^4}{4!}\phi^{IV}(\theta)+\ \ldots\ ]dv+\\&\int_{\frac{b-a}{2}}^{\frac{b+a}{2}}\frac{b+a-2v}{2a}[2\phi(\theta)+\frac{2v^2}{2!}\phi^{II}(\theta)+\ \ldots\ ]dv\end{aligned}\right\}\tag{2}$$

which on integration gives

$$F(\theta)=A\phi(\theta)+B\phi^{II}(\theta)+C\phi^{IV}(\theta)+D\phi^{VI}(\theta)+\ \ldots\ .\tag{3}$$

the desired expression where

$$\left.\begin{aligned}A&=\frac{1}{(2)^1\cdot 2!a}[(b+a)^2-(b-a)^2]\\B&=\frac{1}{(2)^3\cdot 4!a}[(b+a)^4-(b-a)^4]\\C&=\frac{1}{(2)^5\cdot 6!a}[(b+a)^6-(b-a)^6]\\D&=\frac{1}{(2)^7\cdot 8!a}[(b+a)^8-(b-a)^8]\end{aligned}\right\}\tag{4}$$

[1] In this analysis it is assumed that $b\geq a$, since there would probably be no reason why a should be larger than b in practice. Moreover, the corrections for a given value of $a+b$ and for a given ratio $\frac{b}{a}=k$ are precisely the same as those for $\frac{a}{b}=k$, if $a+b$ remains constant.

Expression of $\phi(\theta)$ in terms of $F(\theta)$.—To this end consider the function $F(\theta+c)$. In a manner similar to that followed above for the expression of $F(\theta)$ in terms of $\phi(\theta)$ there results

$$F(\theta+c)=A\phi(\theta+c)+B\phi^{II}(\theta+c)+C\phi^{IV}(\theta+c)+ \ldots . \tag{5}$$

where

$$\left.\begin{aligned}\phi(\theta+c)&=\phi(\theta)+c\phi^{I}(\theta)+\frac{c^2}{2!}\phi^{II}(\theta)+\frac{c^3}{3!}\phi^{III}(\theta)+ \ldots .\\ \phi^{II}(\theta+c)&=\phi^{II}(\theta)+c\phi^{III}(\theta)+\frac{c^2}{2!}\phi^{IV}(\theta)+ \ldots .\end{aligned}\right\} \tag{6}$$

Substitution of these values of $\phi(\theta+c)$, $\phi^{II}(\theta+c)$, etc., in equation (5) gives

$$\left.\begin{aligned}F(\theta+c)=A(\phi\theta)+Ac\phi(\theta)+&\left(\frac{Ac^2}{2!}+B\right)\phi^{II}(\theta)+\left(\frac{Ac^3}{3!}+Bc\right)\phi^{III}(\theta)+\\ &\left(\frac{Ac^4}{4!}+\frac{Bc^2}{2!}+c\right)\phi^{IV}(\theta)+\left(\frac{Ac^5}{5!}+\frac{Bc^3}{3!}+Cc\right)\phi^{V}(\theta)+\\ &\left(\frac{Ac^6}{6!}+\frac{Bc^4}{4!}+\frac{Cc^2}{2!}+D\right)\phi^{VI}(\theta)+ \ldots .\end{aligned}\right\} \tag{7}$$

Similarly,

$$F(\theta-c)=A\phi(\theta)-Ac\phi(\theta)+\left(\frac{Ac^2}{2!}+B\right)\phi^{II}(\theta)-\left(\frac{Ac^3}{3!}+Bc\right)\phi^{III}(\theta)+\ldots . \tag{8}$$

If $\Delta^2F(\theta)$ is defined as follows

$$\Delta^2F(\theta)=F(\theta+c)+F(\theta-c)-2F(\theta),$$

there results from equations (3), (7), and (8)

$$\Delta^2F(\theta)=B'\phi^{II}(\theta)+C'\phi^{IV}(\theta)+D'\phi^{VI}(\theta)+ \ldots . \tag{9}$$

where

$$\left.\begin{aligned}B'&=\frac{2Ac^2}{2!}\\ C'&=2c^2\left(\frac{Ac^2}{4!}+\frac{B}{2!}\right)\\ D'&=2c^2\left(\frac{Ac^4}{6!}+\frac{Bc^2}{4!}+\frac{C}{2!}\right)\end{aligned}\right\} \tag{10}$$

From equation (9) it follows that

$$\Delta^2F(\theta+c)=B'\phi^{II}(\theta+c)+C'\phi^{IV}(\theta+c)+D'\phi^{VI}(\theta+c)+ \ldots . \tag{11}$$

Substituting for $\phi^{II}(\theta+c)$, $\phi^{IV}(\theta+c)$, etc., the values given in equations (6)

$$\left.\begin{aligned}\Delta^2F(\theta+c)=\frac{B'}{C'}\phi^{II}(\theta)+\frac{B'c}{1!}\phi^{III}(\theta)+\left(\frac{B'c^2}{2!}+\frac{C'}{1}\right)\phi^{IV}(\theta)+\\ \left(\frac{B'c^3}{3!}+\frac{C'c}{1!}\right)\phi^{V}(\theta)+\ \ldots\ .\end{aligned}\right\} \tag{12}$$

In a similar way

$$\left.\begin{aligned}\Delta^2F(\theta-c)=\frac{B'}{1}\phi^{II}(\theta)-\frac{B'c}{1!}\phi^{III}(\theta)+\left(\frac{B'c^2}{2!}+\frac{C'}{1}\right)\phi^{IV}(\theta)-\\ \left(\frac{B'c^3}{3!}+\frac{C'c}{1!}\right)\phi^{V}(\theta)+\ \ldots\ .\end{aligned}\right\} \tag{13}$$

Defining $\Delta^4F(\theta)$ as follows:

$$\Delta^4F(\theta)=\Delta^2F(\theta+c)+\Delta^2F(\theta-c)-2\Delta^2F(\theta)$$

there results by substitution from equations (9), (12), and (13)

$$\Delta^4F(\theta)=C''\phi^{IV}(\theta)+D''\phi^{VI}(\theta)+,\ \text{etc.} \tag{14}$$

where

$$\left.\begin{aligned}C''&=2c^2\frac{B'}{2!}\\ D''&=2c^2\left(\frac{B'c^2}{4!}+\frac{C'}{2!}\right),\ \text{etc.}\end{aligned}\right\} \tag{15}$$

In a quite similar way expressions may be obtained for $\Delta^6F(\theta)$, $\Delta^8F(\theta)$, etc., in terms of $\phi^{VI}(\theta)$, $\phi^{VIII}(\theta)$, etc., and constants. It is then possible to evaluate $\phi^{II}(\theta)$, $\phi^{IV}(\theta)$, etc., of the right-hand member of equation (3) in terms of $\Delta^2F(\theta)$, $\Delta^4F(\theta)$, etc., with the following result [see equations (9) and (14)]:

$$\phi(\theta)=\frac{1}{A}[F(\theta)-K\Delta^2F(\theta)+L\Delta^4F(\theta)+\ \ldots\ .] \tag{16}$$

where

$$\left.\begin{aligned}K&=\frac{B}{B'}\\ L&=\frac{BC'-B'C}{B'C''}\end{aligned}\right\} \tag{17}$$

[For the case where $b=a$ and where the sensibility-curve of the eye does not enter, so that $\psi(\theta)=\text{constant}=1$, there follows

$\phi(\theta)=f(\theta)$, and equation (16) reduces to Runge's expression for the correction in spectrometry with the linear bolometer or thermopile

$$af(\theta)=2\left\{\frac{F(\theta)}{2!}-\frac{1}{4!}\Delta^2F(\theta)+\frac{(2!)^2}{6!}\Delta^4F(\theta)-,\text{ etc.}\right\} \tag{18}$$

Expression of $f(\theta)$ in terms of $F(\theta)$.—Thus far only the spectrum of a single source has been considered, and the analysis has led to an expression of the luminosity of the pure spectrum $[\phi(\theta)]$ in terms of the luminosity of the impure spectrum $[F(\theta)]$. From the definition $\phi(\theta)=\psi(\theta)f(\theta)$ it is seen that the determination of $f(\theta)$, the intensity in the pure energy spectrum, in terms of the measured $F(\theta)$, necessitates a knowledge of the sensibility function $\psi(\theta)$ under the conditions under which $F(\theta)$ was measured. The same result may be accomplished, however, in a simpler way.

In spectro-photometry one is concerned with the relative intensities of two spectra, rather than with the absolute intensity of one. If the substitution method of measurement is employed one determines the impure luminosity-curve of one source, represented by the function $F(\theta)$, in terms of the impure luminosity-curve $F_0(\theta)$ of some other source, which may for simplicity be called the standard source, through the medium of the impure luminosity-curve $F'(\theta)$ of some third comparison source. The pure energy-curve of the standard source, represented by $f_0(\theta)$, is presumably known, and from this it is desired to determine the corresponding function $f(\theta)$ of the test source. *If the comparison spectrum is maintained absolutely constant* throughout the intercomparison of the test and standard sources (which condition involves the constancy of the slit-widths b and a') then $\psi(\theta)=\psi_0(\theta)=\psi'(\theta)$, and so

$$\frac{\phi(\theta)}{\phi_0(\theta)}=\frac{f(\theta)}{f_0(\theta)} \tag{19}$$

from which

$$f(\theta)=f_0(\theta)\frac{\phi(\theta)}{\phi_0(\theta)} \tag{20}$$

Substituting in equation (2) for $\phi(\theta)$ and $\phi_0(\theta)$ their values as given in equation (16), and remembering [equation (4)] that $A=A_0=b$, there follows:

$$f(\theta)=f_0(\theta)\frac{F(\theta)-K\Delta^2F(\theta)+L\Delta^4F(\theta)+,\text{ etc.}}{F_0(\theta)-K_0\Delta^2F_0(\theta)+L_0\Delta^4F_0(\theta)+,\text{ etc.}} \tag{21}$$

But the actual quantities determined in the spectro-photometric measurements are

$$\left.\begin{aligned} R(\theta) &= \frac{F(\theta)}{F'(\theta)} \\ R_0(\theta) &= \frac{F_0(\theta)}{F'(\theta)} \end{aligned}\right\} \quad (22)$$

so that

$$\left.\begin{aligned} F(\theta) &= R(\theta)F'(\theta) \\ F_0(\theta) &= R_0(\theta)F'(\theta) \end{aligned}\right\} \quad (23)$$

Substituting these values in equation (21) there follows

$$f(\theta) = f_0(\theta)\frac{R(\theta)F'(\theta) - K\Delta^2[R(\theta)F'(\theta)] + L\Delta^4[R(\theta)F'(\theta)] +, \text{ etc.}}{R_0(\theta)F'(\theta) - K_0\Delta^2[R_0(\theta)F'(\theta)] + L_0\Delta^4[R_0(\theta)F'(\theta)] +, \text{ etc.}} \quad (24)$$

where K and L, and K_0 and L_0 are given by equations (17), (15), (10), and (4) in terms of the constant slit-width b of the telescope and the slit-width of the collimator, respectively taken as a and a_0. for the test and standard sources.[1]

In equation (24) the function $f(\theta)$, giving the distribution of energy in the pure spectrum of the test source, is expressed in terms of known or measurable quantities. The function $f_0(\theta)$ for the standard source is presumably known; $R(\theta)$ and $R_0(\theta)$ are the ordinary spectro-photometric ratios where the substitution method is employed; $F'(\theta)$, the luminosity of the impure spectrum of the

[1] Various investigators have found indications of a lack of proportionality between the apparent flux of light through the collimator slit of a spectro-photometer and the width of the slit, even though the slit is of the Vierordt type having bilateral motion. From the theory developed in this paper such a result is to be expected for all wave-lengths except in those regions of the spectrum where the impure luminosity-curve is a straight line. But Murphy (*Astrophysical Journal*, **6**, 9, 1897) finds lack of proportionality even at these wave-lengths, and ascribes the discrepancy to diffraction. In order to clear up this point very careful measurements were made at the wave-length $\lambda = 0.57\mu$ at which for our conditions the impure luminosity-curve is a straight line. An extended source (the illuminated magnesium carbonate block) was used, and readings were made for slit-widths ranging from 0.05 mm up to 0.4 mm, the observed luminosity being maintained constant by the variable sectored disk. Under these carefully prescribed conditions there was an apparent lack of proportionality if the drum readings were taken as giving the slit-width; but a careful calibration of the slit with a micrometer microscope showed the drum readings to be in error by such an amount that the proportionality was established when the corrected slit-widths were taken.

comparison source, remains to be determined. The curve representing this function may be obtained by a direct measurement, using either the spectro-photometer (at least this measurement can be made in the Schmidt & Haensch form of the Lummer-Brodhun spectro-photometer) or some other suitable instrument, or it may be computed from the known energy-curve of the source, together with the dispersion-curve of the spectro-photometer prism and the proper sensibility-curve of the eye. The requisite accuracy in the determination of $F'(\theta)$ will be discussed later in considering numerical results.

C. APPLICATION TO SPECTRO-PHOTOMETRIC MEASUREMENTS

In applying equation (24) to spectro-photometric measurements it is assumed that the energy distribution $f_0(\theta)$, in the pure spectrum of the so-called standard source, the luminosity distribution $F'(\theta)$ in the impure spectrum of the comparison source, and the luminosity ratios $R(\theta)$ and $R_0(\theta)$ are known continuous functions. It is further assumed that $R(\theta)$ and $R_0(\theta)$ were determined under the prescribed condition that $F'(\theta)$ remained constant throughout the measurements, this condition implicitly involving the constancy of the two slit-widths b and a'. Supposing the constants K, K_0, L, and L_0 to have been evaluated, the application of equation (24) is made as follows:

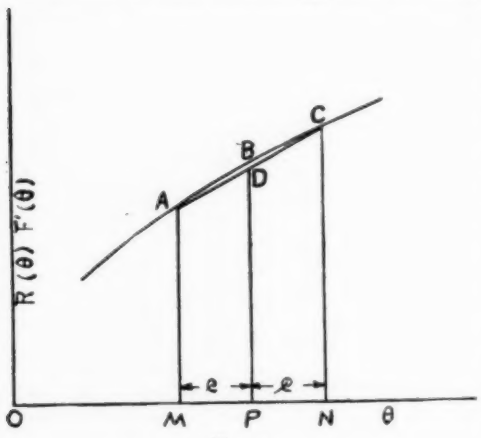


FIG. 2

Form the two functions $[R(\theta)F'(\theta)]$ and $[R_0(\theta)F'(\theta)]$ and plot them as functions of θ as illustrated in Fig. 2. If $\overline{BP}$ represents the value of this function for some value of θ given by $\overline{OP}$, and if $\overline{AM}$

and $\overline{CN}$ represent values of the function corresponding to $\theta+c$ and $\theta-c$, where c is expressed in the same angular unit as θ, then

$$\Delta^2[R(\theta)F'(\theta)] = -2\overline{BD} \tag{25}$$

In a similar way, from the curve representing the function $\Delta^2[R(\theta)F'(\theta)]$ the numerical values of $\Delta^4[R(\theta)F'(\theta)]$ are obtained. From the values of $\Delta^2[R(\theta)F'(\theta)]$ and $\Delta^4[R(\theta)F'(\theta)]$ the numerator of the right-hand member of equation (24) is computed for all values of θ; and in a quite similar way the denominator is evaluated. Hence $f(\theta)$ is known at once in terms of $f_0(\theta)$. If there were no slit-width correction equation (24) would be

$$f(\theta) = f_0(\theta)\frac{R(\theta)}{R_0(\theta)} \tag{26}$$

If we denote by δ the correction evaluated in the way outlined above, equation (24) may be written in this form:

$$f(\theta) = f_0(\theta)\frac{R(\theta)}{R_0(\theta)}(1+\delta) \tag{27}$$

D. NUMERICAL RESULTS FOR BLACK-BODY SPECTRA

As was stated in the introduction, the preceding theory was developed in order to determine with greater accuracy from spectro-photometric measurements the energy distribution in the spectrum of a black body at some temperature, say 2500° Abs., assuming as known the energy distribution in the spectrum of the black body at some other temperature, say 1500° Abs. The correction factors, δ, [equation (27)] have been evaluated for spectro-photometric intercomparisons of black-body spectra at different temperatures and under different conditions of collimator and telescope slit-width.

The results are plotted in Figs. 3 and 4. In Fig. 3 the abscissas are wave-lengths and the ordinates are values of δ expressed in per cent for the intercomparison of the spectrum of a black body at 1500° Abs. with that of a black body at the following temperatures: 1800° Abs. (curve *a*), 2000° Abs. (curve *b*), and 2500° Abs. (curve *c*), in each case under the slit-width condition that $a=b=0°.1$ ($=0.4$ mm approximately). $f_0(\theta)$ and $R_0(\theta)$ refer to the black

body at 1500° Abs. and $f(\theta)$ gives the pure energy distribution for the black body at the higher temperatures. By reference to curve *c* it is seen at once that the relative intensity of energy emission in wave-lengths 0.5 μ and 0.66 μ in the case of a black body at 2500° Abs. as determined from spectro-photometric comparison with a

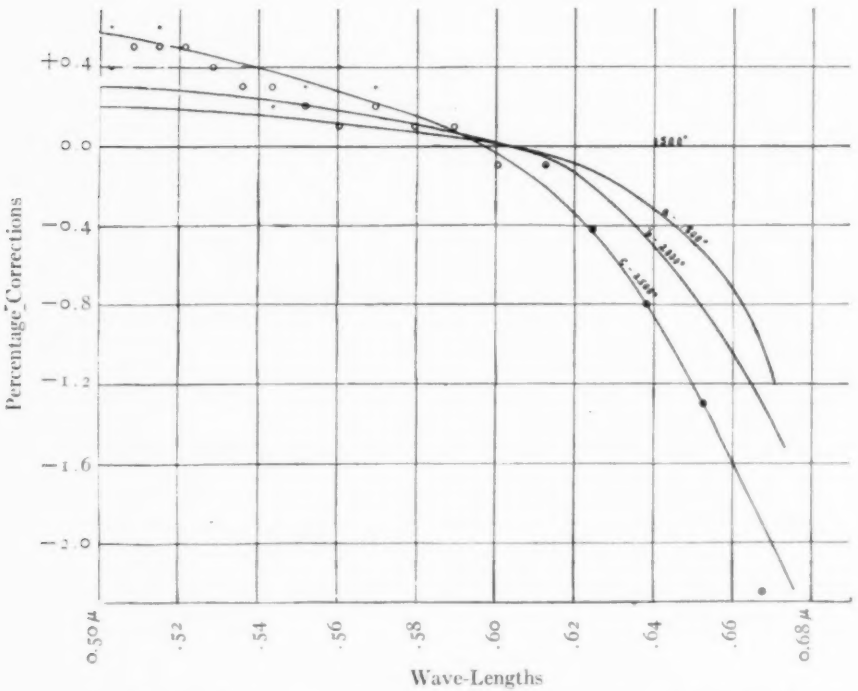


FIG. 3.—Percentage corrections to energy-curves of a black body at various temperatures as determined through comparison with that of a black body at 1500° Abs., when the collimator and telescope slits are each equal to 0.1 (0.4 mm approximately).

+ Data based on visibility-curve of A. W. (Some of these defective on engraving.)
o Data based on visibility-curve of A. K.

black body at 1500° Abs. is in error by 2.2 per cent ($\delta = +0.5$ per cent at $\lambda = 0.5\,\mu$, and $\delta = -1.7$ at $\lambda = 0.66\,\mu$) and needs to be corrected by that amount. Similar but smaller errors enter for intercomparisons at smaller temperature differences but even when the temperature differences are only 400° or 500° the corrections are

appreciable and should be allowed for in accurate work where the attempt is made to keep the errors within one per cent.

The values of δ plotted in Fig. 3 are for the case where the collimator and telescope slit-widths are equal to each other and each is equal to 0°.1 (=0.4 mm, approximately). As either slit-width is increased the values of δ also increase. Thus Fig. 4 shows

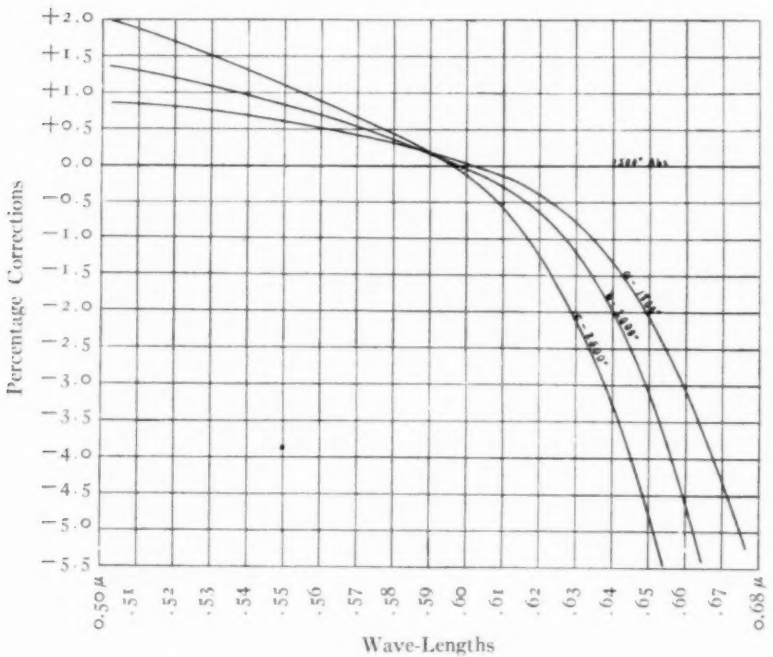


FIG. 4.—Percentage corrections to energy-curves of a black body at various temperatures as determined through comparison with that of a black body at 1500° Abs., when the collimator and telescope slits are each equal to 0°.2 (0.8 mm approximately).

curves similar to those given in Fig. 3, except that the slit-widths are twice as wide, each equaling 0°.2 or 0.8 mm, approximately. The values of δ, and hence the errors under these circumstances are about four times as large as the corresponding values of δ for $a=b=0°.1$. In intercomparing the spectra of two black bodies at 1500° and 2500° Abs. the relative errors between the two wave-lengths $\lambda=0.5\,\mu$ and $\lambda=0.66\,\mu$ amount to approximately 9 per

cent. Even when the temperature difference is only 200° or 300° the correction becomes appreciable in accurate work when the slit-widths are as large as 0.8 mm.

When $a+b$ remains constant, but the relative values of a and b change, the values of δ again undergo a change. Thus, consider

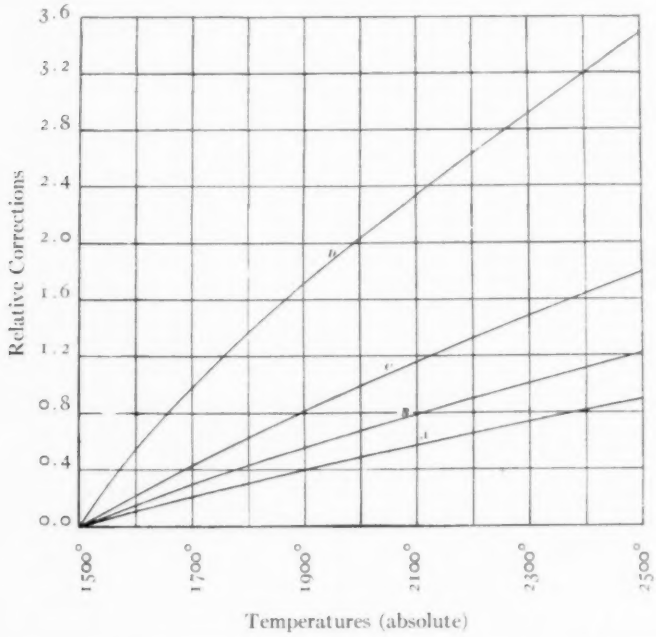


FIG. 5.—Relative corrections at $\lambda=0.625\ \mu$ and $\lambda=0.5\ \mu$ to the energy-curves of a black body at various temperatures obtained through comparison with that of a black body at 1500° Abs.

Curve A, $a+b=0^{\circ}.2$; $\frac{b}{a}=1$ Curve C, $a+b=0^{\circ}.2$; $\frac{b}{a}=\infty$

Curve B, $a+b=0^{\circ}.2$; $\frac{b}{a}=4$ Curve D, $a+b=0^{\circ}.4$; $\frac{b}{a}=1$

the errors in the relative emission at the two wave-lengths $0.625\ \mu$ and $0.5\ \mu$ for various temperatures and various values of a and b. Data of this nature are given in Fig. 5 in which the ordinates are $\delta_{0.625\mu}-\delta_{0.5\mu}$ and the abscissas are temperatures between which and 1500° Abs. the comparisons are made. Curves are plotted for the following cases:

Curve *A*; $a+b=0^{\circ}.2$; $\frac{b}{a}=1$

Curve *B*; $a+b=0^{\circ}.2$; $\frac{b}{a}=4$

Curve *C*; $a+b=0^{\circ}.2$; $\frac{b}{a}=\infty$

Curve *D*; (for comparison) $a+b=0^{\circ}.4$; $\frac{b}{a}=1$

It is thus seen that as the ratio $\frac{b}{a}$ differs from unity, $a+b$ remaining constant, the error increases until $\frac{b}{a}=\infty$ when the error is about twice that at $\frac{b}{a}=1$. Curve *D* for $\frac{b}{a}=1$ but $a+b=0^{\circ}.4$ is given for comparison.

If the curves of Fig. 5 had been plotted for the two wave-lengths 0.66 μ and 0.5 μ instead of 0.625 μ and 0.5 μ, the corrections would have been nearly twice as large (see Figs. 3 and 4), but the uncertainty in the corrections makes it advisable to avoid the extreme wave-lengths at the red end of the spectrum. In this region the rapid change in the sensibility-curve combined with the increasing energy and the relatively small dispersion makes the correction relatively large and difficult of evaluation.

From a consideration of the data given in the three preceding figures it is evident that quite appreciable errors may occur in the determination of the energy-curve of a black body at one temperature from the energy-curve of a black body at another temperature by means of spectro-photometric comparisons, since it is not unusual that the slit-widths of the collimator and telescope are of the order of magnitude of 0.4 to 0.8 mm.

It is to be noted that when the energy-curve of a black body at any temperature is determined from spectro-photometric comparison with a black body at a *lower* temperature the correction for impurity of spectrum is always such as to *increase* relatively the *blue* end of the computed energy-curve.

The question of the accuracy to which $F'(\theta)$ must be known was raised in an earlier part of the paper. An answer to this is found in curve *c*, Fig. 3. The points plotted thus, "o," were obtained on

the basis of one $F'(\theta)$ curve, and the points plotted thus, "+," were obtained on the basis of another somewhat different curve of $F'(\theta)$. These two curves of $F'(\theta)$ are shown in Fig. 6, and it is evident that the curve of $F'(\theta)$ need not be determined with extreme accuracy

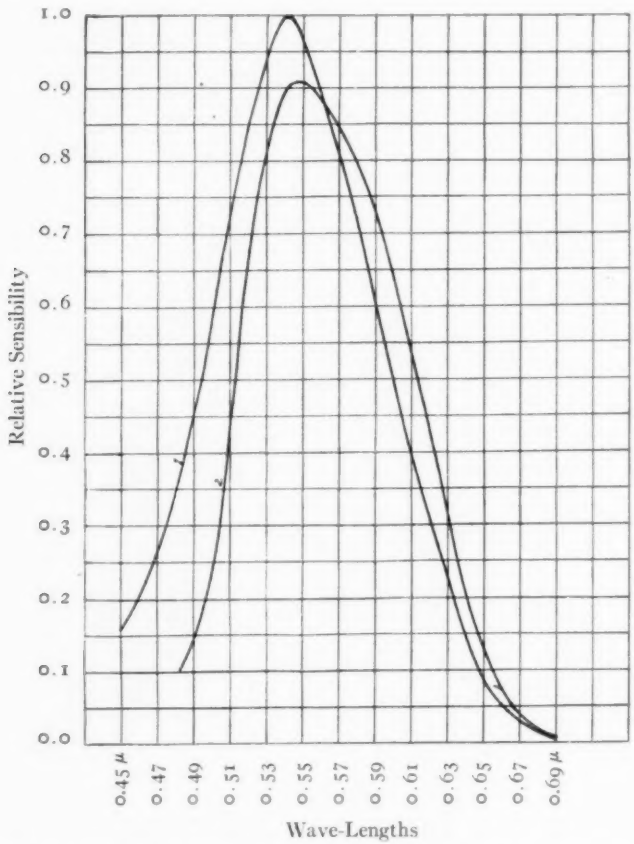


FIG. 6.—Sensibility-curves corresponding to luminosity distribution in spectrum of a black body at 1500° Abs.

Curve 1, Observer K. Curve 2, Observer W.

in order to compute the values of δ. The reason for this is to be found in the use of the same $F'(\theta)$ curve in both the numerator and denominator of equation (24). On the other hand, small errors in the two curves representing $R(\theta)$ and $R_0(\theta)$ render difficult the

determination of $\Delta^2[R(\theta)F'(\theta)]$, $\Delta^2[R_o(\theta)F'(\theta)]$, $\Delta^4[R(\theta)F'(\theta)]$, etc. The numerical data given in this paper were computed assuming the Planck equation for spectral energy distribution. In correcting the relative energy-curves of two incandescent solids with spectra similar to those of a black body, it is probable that higher accuracy

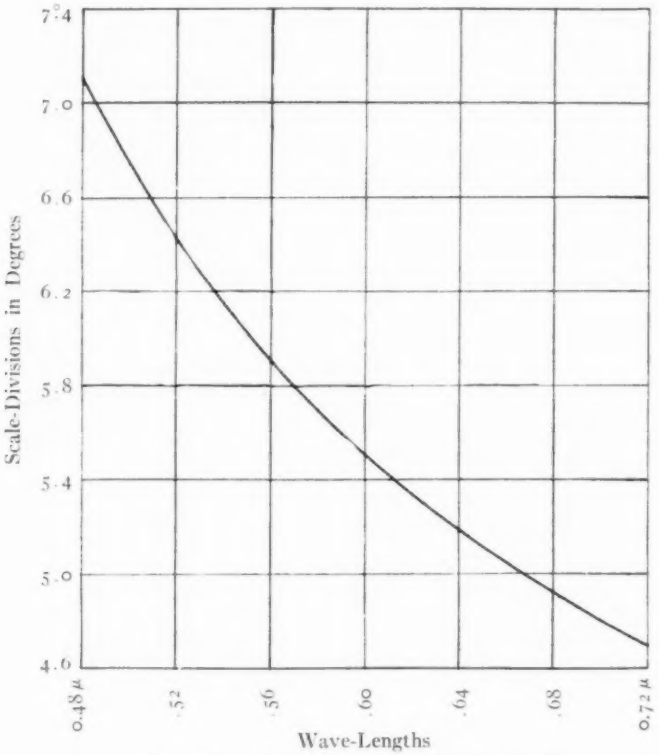


FIG. B.—Calibration-curve of dispersing prism

will result if the correction terms are approximated from the curves given in this paper for a black body, rather than if an attempt is made to compute them directly from the observed ratios $R(\theta)$ and $R_o(\theta)$.[1] Thus, if one incandescent solid has a luminosity-curve

[1] In order that anyone may be better able to determine the applicability of the numerical results given in this paper to his work the calibration-curve of the dispersing prism is given in Fig. B.

quite similar to that of a black body at 1800°, and another solid has a curve similar to that of a black body at 2300°, the corrections will be very nearly the same as those for two black bodies at 1800° and 2300°.

Although all the data given in the various curves of the different figures were computed rather than observed, the following experiment gives a general experimental confirmation of the deductions. If two black-body spectra, one corresponding to a black body at 2100° or 2200° Abs. and the other to a black body at 1700° or 1800° Abs., are intercompared by the substitution method, first, when the collimator and ocular slits are each 0.4 mm and then when they are each 0.8 mm, the comparison spectrum remaining constant, the spectro-photometric ratios under the two circumstances should be different by an amount readily discernible. Thus, if R_{λ_1} is the ratio of the luminosity of the black body at the high temperature to that at the low temperature for $\lambda_1 = 0.515\,\mu$ and for slit-width $a = b = 0.4$ mm; R_{λ_2} the corresponding ratio for $\lambda_2 = 0.67\,\mu$; R'_{λ_1} the similar ratio for $\lambda_1 = 0.515\,\mu$, and $a = b = 0.8$ mm; and R'_{λ_2} the corresponding ratio for $\lambda_2 = 0.67\,\mu$; then it should be found according to the theory that

$$\frac{R_{\lambda_1}}{R_{\lambda_2}} = \frac{R'_{\lambda_1}}{R'_{\lambda_2}} \quad (1 + 4 \text{ per cent or } 5 \text{ per cent}).$$

For the two black-body spectra, that of a tungsten lamp at relatively high voltage, and that of a carbon lamp at relatively low voltage, were used, the voltages being chosen to approximate the stated conditions of temperature. The comparison spectrum was maintained constant both in quality and in intensity by making the comparison collimator slit 0.8 mm wide when the ocular slit was 0.4 mm, and 0.4 mm wide when the ocular slit was 0.8 mm. Under these conditions two different observers made measurements which showed the ratios $\frac{R_{\lambda_1}}{R_{\lambda_2}}$ and $\frac{R'_{\lambda_1}}{R'_{\lambda_2}}$ to be different in the direction and by the approximate amount indicated in the above equation.

E. APPLICATION OF SLIT-WIDTH CORRECTIONS IN TEMPERATURE MEASUREMENTS

It is sometimes convenient, as in the author's work on selective radiation, to compute the temperature at which a black body would have a given curve of energy distribution in the visible spectrum, in cases where this energy-curve has been obtained through spectrophotometric comparisons from a known distribution of energy, as of a black body at some known temperature. The magnitude of the error in the computed temperature owing to the error due to impurity of spectrum can readily be evaluated. From Wien's Law

$$J=\frac{C_1}{\lambda^a e^{\frac{C_2}{\lambda T}}} \tag{28}$$

there is obtained on differentiation

$$\frac{dJ}{J}=\frac{C_2}{\lambda T}\frac{dT}{T} \tag{29}$$

For a given percentage change in temperature, $\frac{dT}{T}$, the relative change in intensity at λ_1 compared with the change at λ_2 is given by the equation

$$\left(\frac{dJ}{J}\right)_{\lambda_1}-\left(\frac{dJ}{J}\right)_{\lambda_2}=\frac{C_2}{T}\left(\frac{1}{\lambda_1}-\frac{1}{\lambda_2}\right)\frac{dT}{T}\,. \tag{30}$$

Conversely, if the relative change at λ_1 compared with that at λ_2 is known, i.e., if $\left(\frac{dJ}{J}\right)_{\lambda_1}-\left(\frac{dJ}{J}\right)_{\lambda_2}$ is known, the corresponding change in temperature can be computed. Applied to the slit-width errors

$$\left(\frac{dJ}{J}\right)_{\lambda_1}-\left(\frac{dJ}{J}\right)_{\lambda_2}=\delta_{\lambda_1}-\delta_{\lambda_2} \tag{31}$$

the relative errors at the two wave-lengths λ_1 and λ_2. Hence the percentage error in temperature owing to the slit-width errors is given by the equation

$$\frac{dT}{T}=\frac{\lambda_1\times\lambda_2}{\lambda_2-\lambda_1}\cdot\frac{T}{C_2}(\delta_{\lambda_1}-\delta_{\lambda_2})\,. \tag{32}$$

Thus, suppose λ_1 and λ_2 are taken as $0.5\,\mu$ and $0.66\,\mu$ respectively, and that the intercomparison is made between the spectrum of a

black body at 1500° Abs. and that of a black body at 2500° Abs., the slit-widths being $a=b=0^{\circ}.2$. From Fig. 4, the values of δ are $\delta_{0.5}=+2.0$ per cent and $\delta_{0.66}=-7.0$ per cent so that $\delta_{\lambda_1}-\delta_{\lambda_2}=9.0$ per cent. Moreover, $C_2=14{,}500$ so that equation (32) becomes

$$\frac{dT}{T}=\frac{0.66\times 0.5}{0.66-0.50}\times\frac{2500}{14500}\times 0.09=0.032\,, \tag{33}$$

or 80° in 2500°, a quite appreciable quantity. Hence if the temperature of a black body at 2500° were computed from the spectrophotometric ratios obtained through intercomparison under the stated conditions with a black body at 1500°, it would be found to be 2420° instead of 2500° unless the corrections for slit-width were applied.

It is to be noted that the temperature correction is always in such a direction as to increase the observed difference. Thus, the true temperature is higher than that observed from spectrophotometric comparison with a black body at a lower temperature, and conversely the true temperature is lower than that observed from spectro-photometric comparison with a black body at a higher temperature.

F. SUMMARY

1. Owing to the impurity of the spectrum due to the finite widths of the collimator and ocular slits, it is necessary to correct the relative luminosity-curves of two sources compared in a spectrophotometer in order to determine the true relative energy-curves of the sources.

2. This slit-width correction is most readily applied when the substitution method of measurement is employed, and the comparison spectrum is maintained constant.

3. The correction is less as the slit-widths are less and for any given sum of the two slit-widths, $a+b$, the correction is least where $a=b$.

4. Applied to spectra of the black-body type, the correction is appreciable in accurate work even though the temperature difference between the two sources is only a few hundred degrees, and the slit-widths are quite favorable ($a=b=0.4$ mm). The tem-

perature correction is always in such a direction as to increase the observed difference of temperature.

5. In determining the temperature of a black body at about 2500°, from spectro-photometric comparison with a black body of known temperature of about 1500°, an error of 80° may result if the slit-widths are $a=b=0.8$ mm and the wave-lengths at which the comparison is made are $\lambda_1=0.5\,\mu$ and $\lambda_2=0.66\,\mu$.

PART II. A NEW FORM OF VARIABLE ROTATING SECTORED DISK FOR USE IN SPECTRO-PHOTOMETRY

A. INTRODUCTION

It has been recognized for a long time that in spectro-photometric comparisons, as well as in ordinary photometric measurements, more accurate results in general are attainable if the method of substitution is employed. Any dissymetry in the instrument or any personal idiosyncrasy of the observer is much less productive of error when the two spectra to be compared are formed successively by precisely the same optical system, and are viewed in precisely the same relation to the comparison spectrum. But heretofore apparently no attention has been paid to the necessity of maintaining the comparison spectrum absolutely constant throughout the measurements. It has apparently been a matter of indifference whether the variable sectored disk is placed on the side of the comparison source or on the other side, where the two sources whose spectra are to be compared are successively mounted.

The theory developed in the preceding paragraphs of this paper indicates, however, the necessity of maintaining the comparison spectrum absolutely constant throughout the measurements. The correction for impurity of spectrum in its simplest application involves the luminosity-curve of one of the sources, and further assumes that the luminosity of the comparison spectrum remains constant throughout the measurements. If the luminosity-curve of the comparison source is determined once for all—a rather tedious task under any circumstances—it may be used in much of the spectro-photometric work involving continuous spectra of the general type given by a black body at various temperatures.

If the comparison spectrum is to be maintained constant, however, it becomes necessary to secure the photometric balance by varying the intensity of the test source. If a variable rotating sectored disk is used for this purpose,[1] it must be capable of accurate adjustment over a wide range of openings, particularly at small openings. One is ordinarily more interested in obtaining accurate luminosity values in the region of the spectrum where the luminosity is relatively high. If the sectored disk is used on the comparison side the readings of relatively high luminosity of the test source are made with the sectored disk set at a large angular opening, whereas the readings of relatively low luminosity are obtained by reducing the sectored disk opening to somewhat smaller values. If, on the other hand, the sectored disk is used on the test side the reverse is the case. It hence becomes necessary at times to determine accurately very small transmissions.

The two types of variable sectored disk available for accurate work are the elaborate Lummer-Brodhun sector and the very ingenious sector used in the Brodhun "Strassenphotometer." The former is quite complicated and expensive, whereas the latter is comparatively simple and cheap. But in both forms of disks as regularly designed it is most difficult to make accurate settings at small angular openings because very small angular motions at small openings produce relatively large changes in transmission. Thus, an angular motion of 1° corresponds to a change of 1 per cent in transmission when the total opening is 100°, whereas the same angular motion corresponds to a change of 10 per cent in transmission when the total opening is 10°. On this account it is evidently difficult to make accurate settings at small transmissions of the disk even if the accuracy of the sector openings is not questioned.

As has been explained, when measurements are being made with due consideration of the corrections for impure spectrum, it is frequently necessary to measure small transmissions with high accuracy. It therefore seemed desirable to devise, if possible, a new

[1] The assumption is made that the variable rotating sectored disk gives in general the best results of any of the various methods that are employed for accurately measuring the intensity corresponding to a balance in spectro-photometric comparisons.

form of variable rotating sectored disk which should meet all the requirements demanded in the most accurate spectro-photometric comparisons. Such a disk has been designed and constructed, and has now been used for a considerable time with entire satisfaction.

B. DESCRIPTION OF NEW DISK

The principle on which the new form of disk has been designed is the utilization of openings whose edges are not radial. In all other disks which have been used[1] the angular openings are the same at all radial distances from the center. This is necessary if the beam of light to be intercepted is wide, as in ordinary photometry. But when the width of the beam is reduced to the width of the ordinary slit of a spectro-photometer, the necessity of radial sectors is eliminated. The form of sector which has been found very satisfactory in the new disk is that shown in Fig. 7. At the radial distance a, the total angular opening is approximately 324°, corresponding to a transmission of 90 per cent. At a radial distance b the transmission is zero. Between these two limits all intermediate transmissions are obtained. If then, in some way the disk is made to move back and forth along the line $\overline{CD}$, the slit $\overline{SS}$ of the spectro-photometer collimator can be made to come at any radial distance and hence at any percentage transmission of the disk. This motion is accomplished by mounting the disk-bearings on a carriage which is moved along ways by means of a screw which is supplied with the necessary scales for reading the position of the disk. The

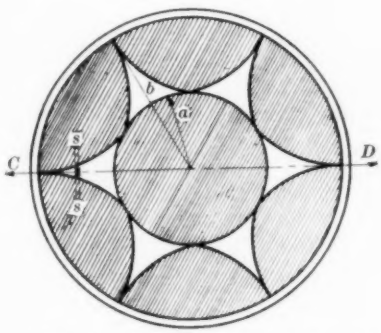


FIG. 7.—Variable sectored disk for spectro-photometer.

[1] Brace devised a rotating sector to be used in calibrating the Vierordt slit of his spectro-photometer which had a number of different angular openings at different radial distances. The changes in angle were made in steps, however, so that for a given step of the disk, say between radii r_3 and r_4, the edges were straight and radial, though the angular opening was not as large as for the next step, between radii r_4 and r_5.

ways are mounted on a casting which is rigidly attached to the base of the spectro-photometer. A photograph of the complete apparatus is shown in Fig. 8.

In an early form of the disk the edges of the sector openings were straight lines, but it was found on computation that the transmission gradient for different radial distances was quite non-

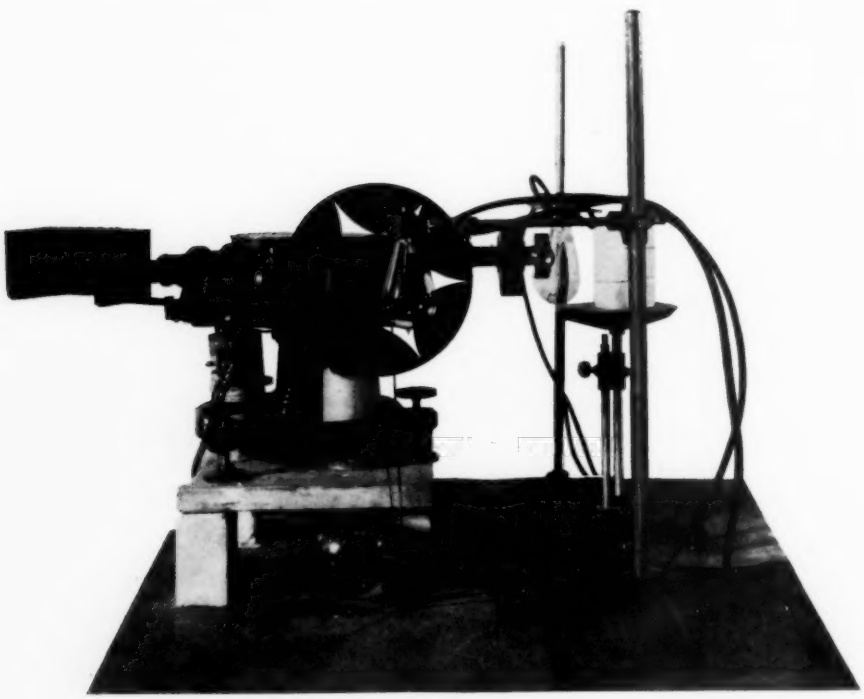


FIG. 8.—The complete apparatus

uniform, particularly near the periphery of the disk, when a slight linear motion of the disk produced a much larger percentage change in transmission than at smaller radial distances.

Since it is desirable, as explained previously, to have the transmission gradient in this region as nearly as possible the same as that in the center of the disk a modified design was sought. Of course it is possible, theoretically, to construct a curve for the edges of the sectors such that the transmission gradient shall be absolutely

constant, but this extreme condition is not necessary. It was found by trial that if the edges of the disk are made arcs of a circle of properly chosen radius the desired end can be approximately attained.

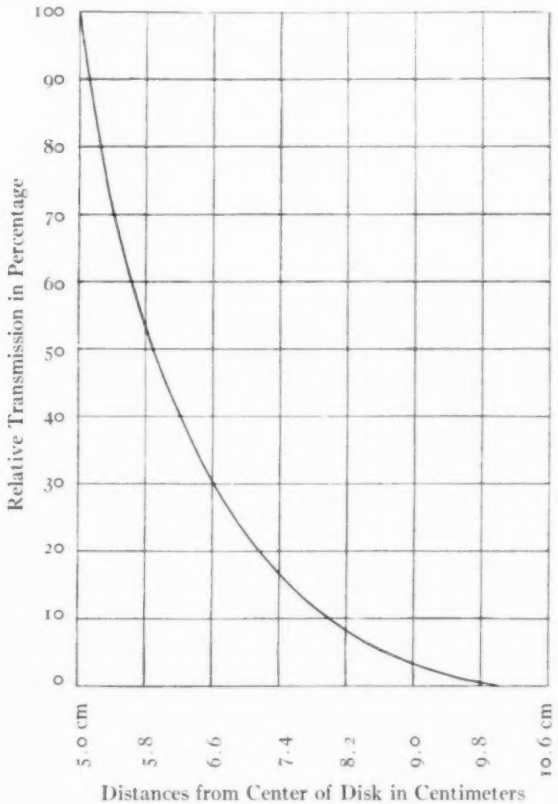


FIG. 9.—Computed transmission-curve for variable sectored disk

In the disk which is shown in the photograph the radius *a* is 5 cm and the radius *b* is 10 cm. For this disk it was found by computation that the most satisfactory results are obtained when the edges of the sectors are arcs of a circle of 10 cm radius. The computed transmission-curve for this disk is shown in Fig. 9 in which the abscissas are linear distances measured from the center of the disk and the ordinates are relative transmissions in terms of the

maximum transmission taken as unity. The curve in which the interest centers, however, is that giving the percentage change in transmission at different relative transmissions corresponding to a linear motion of the disk of some given amount, say 0.1 mm. Such a curve is shown in Fig. 10.

From this curve it is seen that near the center of the disk, i.e., for radial distances of about 6 or 7 cm, a linear motion of 0.1 mm corresponds to a percentage change in transmission of approximately 0.75 per cent. This relative transmission gradient remains fairly constant over a large range of distance or over a range of relative transmissions from about 10 per cent to 100 per cent. At very low transmissions, however, the transmission gradient becomes somewhat steeper, so that at a relative transmission of 5 per cent a

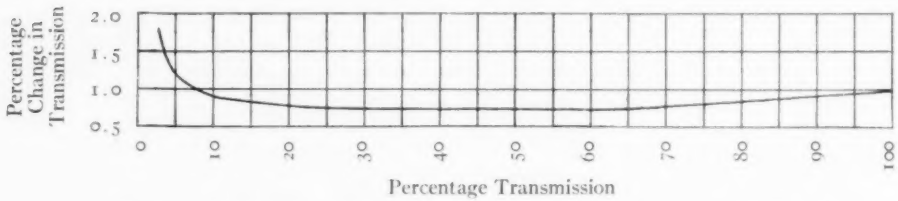


FIG. 10.—Percentage change in transmission corresponding to a linear displacement of 0.1 millimeter.

linear motion of 0.1 mm produces a change in transmission of 1.3 per cent (i.e., 1.3 per cent of 5 per cent) and at 2 per cent transmission it produces a change of 1.7 or 1.8 per cent (i.e., 1.7 or 1.8 per cent of 2 per cent). In other words, throughout the entire range of transmission, from 2 per cent to 100 per cent (relative values) the relative transmission gradient remains of the same order of magnitude, the extreme values being in the ratio of about 2:1. To appreciate the significance of these figures it is only necessary to note that for a corresponding range of relative transmissions for the ordinary types of disks the corresponding ratio of the extreme transmission gradients is about 50:1.

The data given in the above curves were computed on the assumption that the disk was constructed precisely according to specifications. It may be of interest to those who might desire to construct a similar disk to know how the disk was actually con-

structed, and to what accuracy it fulfilled the specifications. The construction of the disk was made possible by the application of a device previously employed in our laboratory in the construction of ordinary disks with sectors having radial edges. This device consists in making the edges separately and mounting them subsequently on the body of the disk which has had cut in it openings slightly larger than those desired in the finished disk. The separate edges can be ground straight or made of any desired shape and then screwed on to the disk body, using a templet in mounting them so as to secure the greatest uniformity and accuracy.

This scheme was employed in constructing the variable sector. The body of the disk was made of aluminium, and the edges were turned out of hard brass, great care being exercised to keep the ends of the individual edges sharp and free from burr, in order that the two edges of each sector could be mounted accurately in contact on the disk body. This precaution is most important. The edges were beveled to prevent reflection, blackened, and then mounted with the aid of a specially designed templet. The completed disk was then attached to a shaft mounted with ball bearings on a carriage, which is movable along a V-shaped track by a carefully ground screw. The position of the disk is read off on a millimeter scale in conjunction with a micrometer attached to the screw-head. The disk is moved back and forth slowly in making a setting by means of the knurled screw-head; but for rapid motion a small crank attached to the shaft of a gear-wheel is provided. The position of the disk can be read to 0.01 mm, and the backlash is negligibly small. The disk is driven by means of a pulley and belt from a small motor placed in a stationary position on the table under the disk.

C. CALIBRATION OF DISK

The disk was calibrated in position by comparison with a number of standardized sectored disks of the ordinary type with fixed openings. Taking the scale-reading of the variable sector for equal transmission with one of the standard disks, say a 90° disk, the scale-readings for other transmissions were obtained, and these were compared by reference to Fig. 9, with the readings that would

have been obtained if the disk had conformed precisely to the specifications. The differences between the observed calibration-curve and the computed curve were found to be too small to be shown definitely on the scale to which the curve in Fig. 9 is drawn. Over about one-half the scale near the middle the differences between the observed and the computed curves were less than 1 per cent, and only at the ends of the scale, i.e., at extreme transmissions, were the errors as large as 1.5 or 2 per cent. Expressed in another way, from the maximum transmission of the disk, which we may call 100 per cent, to a transmission of 5 per cent, on the same relative scale, the difference between the observed and computed curves does not at any point exceed 1.5 per cent of the transmission at that point. The calibration was carried down to 2 per cent or 3 per cent transmission. Even at this minimum transmission the correction was found to be only 2 per cent or 3 per cent of the transmission at this point. The mechanical accuracy obtained by Mr. Würth, the mechanician of the laboratory, in the construction of the disk is thus seen to be very great when one considers the actual magnitude of the sector openings at the low transmissions. Of course even the small errors observed are allowed for in plotting the calibration-curve on a sufficiently large scale, as has been done for our own use.

D. POSSIBLE SOURCES OF ERROR

It is evident at once that a disk of this form is adapted only to those cases where the beam of light to be intercepted is of small dimensions compared with the dimensions of the disk. This is particularly true regarding the width of the beam, but even though the width may be small, one must be careful to see also that the height of the beam is not excessively great. In the case of the ordinary spectro-photometer the height of the collimator slit need give no concern; but the width of the slit needs some further consideration. However narrow the slit for all finite widths, the transmission through one side will be slightly different from that through the other, owing to the transmission gradient of the disk. The question naturally arises as to the effect of this on the indications

of the disk in practice, particularly as the slit-width may necessarily undergo change.

In considering this question it will be assumed that if a variable slit is used on the collimator it will be of the Vierordt double variety, so that the center of the slit may be considered fixed. It is then necessary to consider two cases. If the variable sector is mounted at some distance from the plane of the collimator slit the effect of the transmission gradient of the disk will be, primarily, to produce a non-uniform field, the degree of non-uniformity increasing as the disk is placed farther and farther from the slit. If the disk is mounted at any great distance from the slit, therefore, errors may arise in the indications of the disk, even though one may be able to make some kind of a setting notwithstanding the non-uniformity of the field.

If, on the other hand, the variable disk is placed as close as possible to the plane of the slit, the effect of the transmission gradient will be, not to produce a non-uniform field, but rather to permit relatively more energy of some wave-lengths and relatively less energy of other wave-lengths to penetrate the ocular slit, as compared with the energy of that wave-length in which the image of the collimator slit is formed in the center of the ocular slit. This effect would theoretically affect the luminosity values obtained by the use of the sectored disk, but under all practical conditions the error is negligibly small. Thus, by actual computation it was found that for a collimator slit of 0.4 mm and an ocular slit of 1.0 mm the error in the case of a black-body spectrum is of the order of magnitude of 0.1 per cent. By simple considerations it can readily be seen that under all ordinary conditions the error due to the transmission gradient of the disk is negligibly small. It is seen, therefore, that no appreciable error will result if the precaution is taken to mount the variable sectored disk as close as possible to the plane of the collimator slit. This distance in the case of our own instrument is only 3 or 4 mm.

The only other errors which might possibly enter are that due to back-lash in the motion of the carriage along the screw, and that due to a possible lateral shift of the collimator slit with reference to the disk mounting. It has already been stated that the

former error is negligibly small in the instrument in use in this laboratory. The latter error is mentioned, not because it demands any particular consideration, but rather because it suggests a slight modification in the construction of the Lummer-Brodhun spectro-photometer. In our instrument of this type, made by Franz Schmidt & Haensch, the collimator farther from the telescope is rigidly mounted on the base, but the nearer collimator is adjustable, though without scale for measuring the angular displacements. This flexibility is provided presumably to permit bringing the two spectra in exact juxtaposition. It is useful, however, in measuring the luminosity-curve of a source, though its value in this regard would be greatly enhanced if the position of the movable collimator could be read off a scale.

Another decided improvement would result if the present stationary and movable collimators were interchanged. It is necessary to have the variable sector mounted before the collimator nearer the telescope, but it would be much better if this collimator were rigidly attached to the base of the instrument, and the other collimator were adjustable with an attached index and divided circle to give its position. It would then be much easier to determine a luminosity-curve using the variable sectored disk in making the settings.

E. ADVANTAGES OF NEW TYPE OF DISK

The various features of this new type of disk which should be emphasized as distinct advantages over one or another of the rotating sectored disks at present available, or as valuable characteristics of all satisfactory variable sectors, may be briefly summarized as follows:

1. No selectivity in the transmission.

2. A range of transmission from above 85 per cent to almost 0 per cent. The maximum transmission obtained in any other variable sector within the author's knowledge does not exceed 50 per cent.

3. Continuous and easy adjustment over the entire range of transmission.

4. Applicability in infra-red spectrometry. The absence of

glass which absorbs strongly in the deep infra-red makes this disk peculiarly suitable for measurements of this kind.

5. A nearly uniform relative transmission gradient so that a given angular displacement of the screw-head operating the disk produces approximately the same percentage change in transmission throughout the entire range, except for slight variations at very small transmissions.

6. Because of the properties stated in the preceding paragraph the disk is particularly adapted to spectro-photometric measurements to which the correction for impurity of spectrum is to be applied.

In conclusion the author desires to express his indebtedness to various members of this laboratory for valuable services rendered in connection with the investigation. He is particularly indebted to Dr. C. F. Lorenz and Mr. F. E. Cady for much assistance in the calibration of the variable sectored disk, and to Dr. A. G. Worthing for most of the observations and computations in connection with the slit-width corrections.

PHYSICAL LABORATORY
NATIONAL ELECTRIC LAMP ASSOCIATION
CLEVELAND, OHIO
December 4, 1911

PRESSURE-SHIFT OF SPECTRAL LINES

By W. J. HUMPHREYS

An interesting paper by Sanford[1] has recently appeared with the above title. It is particularly interesting and valuable because of the relations he finds to exist between certain properties of the alkali elements and the shifts of their spectral lines—relations from which he concludes: "Taken all together, there accordingly seems to be a considerable amount of evidence to show that the pressure-shift of spectral lines is related to just those properties of the atom which seem to depend upon the specific inductive capacity."

It was long ago pointed out by the author[2] that: "The shift of similar lines is a periodic function of atomic weight, and consequently may be compared with any other property of the elements which itself is a periodic function of their atomic weights." If this statement is really true, and observations seem still to support it, it follows that the pressure-shift is related to many, possibly all, other properties of the atoms. It is related, not only to just (precisely) "those properties of the atom which seem to depend upon the specific inductive capacity," but also and equally well to just (precisely) all other properties of the atom which, like the above, are periodic functions of the atomic weight. There is therefore no surprise in the relations referred to; in fact three of the six given were mentioned in the paper cited above, but it is important to know as many relations as possible and exactly what they are. Nevertheless, in spite of their importance, it is probable that all such relations are quite too general to show definitely what it is that produces the pressure-shift of spectral lines. Some other test must be found.

The theory that assumes the pressure-change in wave-length to depend upon change in the specific inductive capacity is capable of further development and possibly of a crucial test. But there

[1] *Astrophysical Journal*, **35**, 1, 1912.

[2] *Ibid.*, **6**, 226, 1897.

is at least one serious objection that clings to every form in which this theory has been presented: it does not account for any spreading of the line toward the side of shorter wave-lengths.

Sanford recognizes this difficulty, but attempts to obviate it on the assumption that air molecules weaken the fields of metallic molecules. "If this point of view is correct," he says, "it would seem that the greatest shift toward the red should be due to those atoms in the center of the arc, while the greatest shift toward the violet should be due to atoms around the outer surface."

But many lines give narrow well-defined reversals (due to absorption of light from the center of the arc by material in the outer layers) strongly shifted toward the red, with the rest of the line quite symmetrically spread to either side of the reversal. Maximum emission from the center of the arc and maximum absorption by the material surrounding it seem to coincide in the case of symmetrical lines, whatever the pressure. Fine non-reversed lines of this type, due to traces of the substance in the arc, appear always, under the same pressure, to have the same wave-length as their reversals, though the one must be due essentially to conditions within the arc and the other to conditions in the region immediately surrounding it; nor does this relation of fine lines to their reversals, or even the total shift greatly, if at all, depend upon the material of the electrodes. Hence it appears that the suggested way out of the difficulty is not sufficient.

At one place in his article Sanford says: "All three of the above-mentioned theories [the forced vibration theory, the specific induction theory, and the induction or magnetic theory] make the change in the period of the vibrating mechanism depend upon the proximity of atoms of its own kind, since the greater the atmospheric pressure around the arc the denser must be the metallic vapor in the interior of the arc."

This statement is true enough when the correct interpretation is put upon the expression "its own kind." It is not true, seemingly, that the displacements of iron lines or copper lines, for example, are dependent upon the density of iron or of copper vapor respectively, since lines due to impurities in the arc, as already explained, are displaced equally with the same lines under the same pressure,

whatever the quantity of material present. "Same kind," therefore, should be understood as meaning same in only a very broad sense. According to the magnetic theory it means only that the atoms have individual magnetic fields, and it has nothing to do with what particular element or elements they consist of.

Sanford holds that the magnetic theory of the pressure-shift may be tested by its relation to the magnetic properties of the elements, which properties he says are already known. On applying this test he naturally finds the theory to fail, since the pressure-shifts of the lines due to such strongly magnetic substances as iron, nickel, and cobalt are less than the shifts of lines due to many of the non-magnetic elements.

The author admits of course all these facts, but he holds that they are not conclusive, nor even applicable. It is not the magnetic properties of *cold masses* of the pure elements that are here needed—presumably the ones Sanford had in mind—but the magnetic properties of their *atoms when luminous*.

Now the Zeeman effect shows that the luminous atoms of every element so far examined have magnetic fields of their own. How else could they be acted upon by an outside magnetic field? But it does not show that the iron atom, for instance, has any stronger magnetic field of its own than has a copper atom, and hence we cannot infer, on the magnetic theory, that it would be any more effective than the copper atom in producing pressure-shifts of spectral lines.

Another objection urged against the magnetic theory is the improbability of the powerful magnetic field it demands for the interior of the luminous particle. Frankly, this at first does seem staggering, but to some of us perhaps not one whit more so than does the enormous store of energy experiment demonstrates is locked up within the atoms of many elements—probably within the atoms of all elements. Nor is it any more staggering than the fact that a single atom of iron can give out thousands of independent vibrations at the same time; nor half so staggering as the further fact that it would take one hundred million people something like three hundred years to count the number of complete vibrations produced by an atom of iron in a single second of time. And even

this probably is far too small an estimate, for it leaves out of account the numerous satellites and other complexities of the individual lines; nor is the iron atom by any means the busiest atom known!

It is also interesting to know that the strength of the magnetic fields of the luminous atoms required to account for pressure-shift is of the same order of magnitude as that demanded for them by the theory of Ritz,[1] which, though of subsequent date, was developed from a different standpoint—a theory that explains many phenomena, and, in its general form, has received numerous adherents.

It is true that in details there is not a one-to-one connection between pressure-shift and the Zeeman effect; but in the general phenomena there is a close relation between them. Line spectra show both effects; band spectra, with but few known exceptions, show neither; both increase, in general, with increase of wave-length; both differ in magnitude with different elements, and also with different lines of the same element.

The Saturnian atom accounts for the general phenomena of the Zeeman effect, and it accounts too for the general phenomena of pressure-shift, nor does it demand that in every particular there shall be a one-to-one relation between the two phenomena. Atoms with weak fields, for instance, should show large magnetic separation, but not a correspondingly large pressure displacement due to their mutual interaction. But the complexity of the Zeeman phenomena is not yet fully accounted for by any theory; the structure and motions of the atom are not known. This much however seems certain:

a) The luminous particle, being acted upon by an outside magnetic field, has a magnetic field of its own.

b) Since the luminous particle is affected by an outside magnetic field it must also be affected by the magnetic fields of its neighbors.

On the whole the mutually attracting faces of such particles obviously will be closer together and produce a greater effect than the mutually repelling faces, and therefore, while the lines will be spread in both directions, their maximum intensities will be shifted toward the red to an extent that must increase with increase of pressure.

[1] A. Cotton, *Le Radium*, **8**, 451, 1911.

But is this magnetic effect, which seems to be in the right direction and almost inevitable, of sufficient magnitude? The smallness of the Zeeman separation seems to indicate that it is, though there are many details, both experimental and theoretical, yet to be filled in before the magnetic or any other theory of the pressure displacement of the spectral lines can be fully tested.

In the meantime the author is extremely gratified to know that his tentative theory, which he is ready to modify or discard as the facts may direct, is fulfilling the true function of a theory: stimulating investigation and thereby helping to increase our store of knowledge.

U.S. Weather Bureau
Washington, D.C.
March 1912

ON "EARTH LIGHT," OR THE BRIGHTNESS, EXCLUSIVE OF STAR LIGHT, OF THE MIDNIGHT SKY

By W. J. HUMPHREYS

An attempt was made a few years ago by Professor Newcomb[1] to determine the total light of all the stars. The results were far from being in accord with expectations, especially in respect to the relative brightness of the galactic and non-galactic portions of the sky.

A provisional explanation of the difficulty was made by referring the total light to two sources: direct star light, and indirect or atmospherically diffused star light; but this did not prove to be a sufficient explanation—it did not fully account for the observed phenomena. "On the whole," Newcomb says, "it seems either that my observations are wholly at fault—erroneous by an amount which I should find it difficult to account for—or we must materially modify our conclusions from the combination of star gauges with the existing photometric estimates of star light."

More recently this whole subject has been investigated most carefully by Yntema,[2] who reaches the following conclusions:

1. "The light of the sky at night is composed of two parts, one reaching us directly from the stars, the other resulting from processes in the atmosphere."

2. "The latter, termed 'earth light,' is only partly due to the diffused star light. It seems probable that the rest, wholly or in part, is due to a permanent aurora."

Yntema also finds that:

a) "The general brightness of the sky, being measured by the relative brightness of the North Pole, is variable during the same night."

b) "It is varying from night to night."

c) "The observed brightness increases toward the horizon."

[1] *Astrophysical Journal*, **14**, 297, 1901.

[2] *On the Brightness of the Sky and the Total Amount of Starlight.* Groningen: Gebroeders Hoitsema, 1909.

Yntema's observations were made at Borger, Holland, August 1907—May 1908.

Still more recently, in August 1910, Abbot,[1] using an instrument similar to one of those used by Yntema—a Kapteyn sky photometer—made measurements, from the top of Mount Whitney, Cal., on two successive nights of the relative brightness of the night sky; and also of the total light per square degree in terms of a first-magnitude star.

The results obtained by Abbot on Mount Whitney at an elevation of 4420 meters agree in general with those of Yntema, which were obtained practically at sea level. They are, however, smaller in the ratio of 7 to 10, approximately.

The phenomenon of "earth light" seems therefore to be a thing of the high atmosphere, and to be a very general occurrence both as to time and place. Its variability and its increase with zenith distance seem to preclude attributing it wholly to any celestial or combination of celestial sources, such as diffused star light, reflection and scattering of sun light by meteoric particles and dust, or anything in the nature of the zodiacal light or the *Gegenschein*. On the other hand, Yntema's suggestion that it may be due wholly or in part to a permanent aurora—whatever the cause of this in turn—appears very plausible, and especially so since the green "auroral line," λ 5770, may be seen on almost any dark clear night in any part of the sky.[2] That it is a phenomenon essentially of the upper atmosphere, auroral or what not, seems probable.

If it is wholly of auroral origin it would appear that it should, in general, be brightest in those regions where ordinary auroras are brightest, and faintest in equatorial regions. This question, however, is not definitely answerable from the published data.

Apart from the permanent aurora there is one other source of light—perhaps to some extent of the permanent aurora itself—the possible effect of which it is the specific purpose of this paper to consider.

The source in question is the continual bombardment of the outer atmosphere by material of meteoric origin; including under

[1] *Annual Report Smithsonian Institution*, 1911, p. 64.

[2] W. W. Campbell, *Astrophysical Journal*, **2**, 162, 1895.

this term all particles picked up by the earth in its orbital motion, whether of cosmical, solar, or any other origin. So far as this produces light at all it will be through a considerable depth of the outer rare atmosphere, and hence, in general, must appear somewhat brighter with increase of zenith distance. It should also be nearly independent of any attainable altitude, and therefore, in both particulars, is in accord with observations.

For simplicity of numerical calculations it will be assumed that the "earth light" is of both constant and uniform intensity—the same over all parts of the sky, invariable, and continuous. Obviously these conditions could be met, so far as intensity of light reaching an observer at the surface of the earth is concerned, by a properly illuminated white-mat screen concentric with and some distance above the surface of the earth.

Further, the total amount of light given off by a self-luminous layer of the atmosphere, since it must radiate equally both outward and inward, would be *twice* that diffusely reflected by an equally bright white-mat surface of the same area. Now the amount of "earth light" per square degree is found by Yntema to average, roughly, one-tenth the light from a star of the first magnitude.

This furnishes a means of also comparing the brightness of "earth light" with that of the moon, as follows. When full the moon is equal to a star of -11.77 magnitude, or the equivalent of 120,000 stars of the first magnitude, and covers about 0.2 of a square degree. Hence the full moon is 6×10^6 times brighter than the sky would be if illuminated by "earth light" alone.

It is now possible, and also essential to certain energy calculations to follow, to measure the brightness of "earth light" in terms of meter candles. The brightness of the full moon is the same as that of a white-mat surface illuminated by a 1200 candle-power light at one meter's distance,[1] or, in symbols:

Brightness of full moon = 1200 m.c. (meter candles).

Therefore

Brightness of "earth light" $= 2\times10^{-4}$ m.c.

Now the average velocity of meteoric matter, as it enters the atmosphere, seems to be about the "parabolic velocity" due to the

[1] *Circular of the Bureau of Standards*, No. 28, p. 7, 1911.

sun's attraction at the earth's distance, or roughly 42 kilometers per second. Also the number of such particles appears rapidly to increase with decrease of size, and presumably the number of those that are far too small to produce visible streaks is vastly greater than the number of all combined that are large enough to be individually seen.

Further, any object, however small, entering the atmosphere with so great a velocity is in the condition of being acted upon by a flame of very great temperature—a temperature quite independent of the density of the atmosphere, assuming it of constant composition. Even if the atmosphere were all hydrogen, the entrance of an object into it with the velocity of 42 kilometers per second would produce the same effect as submitting it to equally dense hydrogen at the temperature (computed) of 142,000° C. If the atmosphere were oxygen the computed temperature would be 2,266,000° C. In either case both the velocity and resulting temperature (computed) are far beyond anything of the kind dealt with in the laboratory, except in the case of electrons, α particles and the like; and quite sufficient, as both theory[1] and experiment[2] indicate, to produce abundant ionization.

This then may be, at least in part, the source of the so-called permanent aurora—the origin of the necessary ionization, assuming the green auroral line to be due to electrical discharges.

It is well known that the amount of light that a solid body gives off increases very rapidly with increase of temperature. Hence meteors may be intrinsically brighter than any known artificial source. At any rate they have the general appearance of stars in rapid motion as their popular name, "shooting stars," indicates. It will therefore be assumed that the distribution of the total energy between heat and light is the same for meteors as it is for the sun. But the solar constant is about 1.92 calories per square centimeter per minute, and this gives, on the surface of the earth, when the sun is overhead, an illumination of 10^5 m.c.[3]

[1] P. G. Nutting, *Astrophysical Journal*, **21**, 400, 1905.

[2] A. Wehnelt, *Phys. Zeitschr.*, **9**, 134, 1908; O. W. Richardson, *Phil. Trans.*, A, **201**, 497, 1903; and others.

[3] *Circular of the Bureau of Standards*, No. 28, p. 7, 1911.

As seen above, the brightness of "earth light" is 2×10^{-4} m.c., and therefore normal zenith sunshine is 5×10^{8} times brighter than "earth light," and delivers 25×10^{7} times as much energy per square centimeter as is given out from both sides combined per square centimeter of the effective self-luminous shell or surface to which the "earth light" is due.

Hence the total energy used, according to the above assumptions in producing the "earth light" is

$$4\pi R^2\times\frac{1.92}{25\times10^7}\text{ calories per minute,}$$

in which R is the radius of the earth in centimeters, or

$$27\times10^{15}\text{ ergs per second, roughly.}$$

Assuming this energy to be furnished by M grams of matter moving with the velocity of 42 kilometers per second we have,

$$\tfrac{1}{2}MV^2=27\times10^{15}$$

or

$$M=\ 3\times10^{3}\text{, roughly.}$$

While this is nearly 300 times the estimated amount of material in visible meteors, it is less than three times the amount Young[1] assumes as allowable, and, so far as there is any present means of knowing, may be even less than the actual amount of meteoric dust caught up per second by the earth's atmosphere. Indeed it is relatively so small that it would take something like two hundred million years for it to increase the radius of the earth a single centimeter!

But, as stated above, probably a good deal of ionization is produced by the swiftly moving meteoric dust. If such ionization is produced it follows that the radiations thus excited, like those due to ordinary electric discharges in gases, may be largely concentrated in the visible region of the spectrum. Hence the above calculated amount of meteoric matter, 3 kilograms per second, may be more than is actually necessary to generate by the two processes combined, high temperature and electrical discharges, the observed amount of "earth light." In this connection it should be remembered that Yntema's values are distinctly larger than those obtained by most others[2] who have worked on this subject,

[1] *General Astronomy*, p. 475.

[2] C. Fabry, *Astrophysical Journal*, **31**, 394, 1910.

and that therefore the computed amount of energy and meteoric material may be excessive, or, at least, much above the average.

If "earth light" is wholly due, directly or indirectly, or even measurably due to the bombardment of the upper atmosphere by meteoric dust, then it should be brighter, presumably, during the later hours of the night, when the sky overhead is more nearly on the forward side of the earth in its orbital motion. Unfortunately, however, the data at hand are not sufficient for the application of this check to the above theory as to the origin of "earth light." Many more observations are needed for the complete understanding of this faint, but apparently continuous, light; and the above roughly quantitative examination of one probable source of at least some of the light is offered in the hope that it may help to narrow the problem, and even indicate one or two special points to be examined.

CONCLUSION

Numerical calculations indicate that it is within the bounds of reason to assume "earth light" somehow due to bombardment of the outer atmosphere by fine meteoric material.

U.S. WEATHER BUREAU
WASHINGTON, D.C.
March 1912

ON A POSSIBLE ORIGIN OF THE SPECTRUM LINES NEAR THE POLES OF A METALLIC ARC

By R. ROSSI

It has been noted by several observers[1] that spark lines which appear in arc spectra between metallic electrodes are often stronger near the tips of the poles than near the middle; and the term "polar lines" was introduced by Duffield to distinguish them from the lines which appear at the center of either arc or spark and which he denoted by "median lines."

Like all spark lines in arcs, the polar lines are stronger and more numerous in the ultra-violet regions of the spectrum; and are usually sharp, while the median lines are often nebulous. As to their intensity at the two tips of the electrodes, the observations so far obtained are discordant. Fowler, working with an iron arc in the green region, found them stronger near the positive pole than near the negative; Duffield, in an iron arc in the ultra-violet, got them of equal intensity at the two tips, while Barnes, experimenting on a magnesium line, found it stronger near the cathode.

Several explanations have been offered by various authors to account for the origin of polar lines. Duffield in summarizing them shows that temperature as the cause for their production can be rejected; further, that although pressure and density may take some part in the phenomenon they can but doubtfully account for it. There are only the electrical conditions of the arc in its various parts left to be considered as a possible cause for the production of such lines.

The most striking features of the distribution of electricity in an electric arc are the very steep potential gradients near the poles and the very slight fall of potential along its central part. In a carbon arc there is a large potential fall near the anode (about 35 volts), a smaller one near the cathode (about 9 volts), and a gentle potential gradient along its center.

[1] J. Barnes, *Astrophysical Journal*, **21**, 74, 1905; A. Fowler, *Monthly Notices R.A.S.*, **67**, 154, 1907; W. G. Duffield, *Astrophysical Journal*, **27**, 260, 1908; P. G. Nutting, *ibid.*, **28**, 66, 1908.

The rapid potential drops near the poles extend over a very short distance, amounting to a small fraction of the length of the arc, so that, although the potential gradient of an electric arc is often spoken of as about 80 volts per centimeter, in some parts of the arc it may be of the order of as much as 1000 volts per centimeter, i.e., almost comparable with that of a spark. It is known[1] that when the current is increased in a carbon arc a decrease of the potential difference between the poles takes place. For high currents, however, and small arcs this decrease is more prominent at the negative pole than at the positive, the potential gradient in the center remaining practically unaffected. Hence if the polar lines were due to potential gradients and if a metallic arc behaves like a carbon one, by taking photographs of ultra-violet spectra first with small currents and then with large currents, a slight enhancement of the polar lines near the positive pole relative to the negative ought to be noticed in the second case.

Photographs of an iron arc fed by currents varying from 2.5 to 18 amperes were taken in the first order of a $21\frac{1}{2}$-foot concave grating, the astigmatism in that region being not very troublesome. These first photographs proved encouraging, the ends of the polar lines near the positive pole being usually stronger than the ends near the negative at high currents, while they were practically always of equal intensity for small currents. The effect was not quite so marked when the positive pole was below, some convection currents probably taking place in the arc. (Something similar has been noted by Huff[2] in a carbon arc.) In the case of the metallic arcs of iron, nickel, and copper it was subsequently found that when the positive pole is below, the arc is less steady, less luminous, and uses slightly less current than when the positive terminal is above. It will be shown later that when some electrical investigations were made on these arcs, some changes also took place in the electrical distribution according as the positive pole was above or below.

For the sake of getting rid of the astigmatism completely, the taking of the grating photographs was discontinued and a Fuess

[1] Mrs. Ayrton, *The Electric Arc*, chap. vii.

[2] *Astrophysical Journal*, **28**, 59, 1908.

quartz spectrograph used instead. A large number of photographs were taken with an iron arc, with the positive pole above and below, for arcs of different lengths (2.5 to 7 mm) and different currents (2 to 18 amperes). The exposure was always begun after the arc had been started. For the majority of cases especially at high currents the lines were stronger near the positive pole. The strong portion began at the tip of the line, extended over a short length, and then the intensity decreased abruptly. It was subsequently found that this strong part of the line was due to the end of the red-hot globule or drop of molten iron oxide (according as the positive pole is below or above) from which the arc starts at the positive terminal. By screening the slit from the image of the arc and projecting on it the molten globule only, it was found that the spectrum yielded was a faint continuous one, but superimposed on it was a strong iron spectrum. (This probably accounts for the lines being stronger near the positive pole in the grating photographs, the astigmatism masking the cause of the phenomenon.) On this account a very large number of photographs had to be discarded and observations taken only on the few which had not been contaminated by this globule spectrum. Nickel also showed in a few cases the same effect but never to such a degree as iron, while the copper photographs were only very rarely affected by it.

The copper photographs were rather interesting (Plate XIV) inasmuch as some lines appeared only near the negative electrode, and it was only when the positive pole was below and very high currents were used that they faintly appeared at the positive electrode. They are essentially spark lines and do not appear in Kayser and Runge's or Exner and Haschek's wave-length tables for arc spectra; their relative intensities in the arc are practically identical with those in the spark. The following is a list of the most prominent ones, the wave-lengths of which were taken from the latter authors' tables for spark spectra.

2376.43	2526.79	2666.52
2403.51	2529.50	2689.56
2424.62	2545.02	2701.21
2473.55	2590.75	2703.42
2485.99	2599.03	2713.76
2506.51	2600.49	

Altogether 32 good photographs were taken for iron, 14 for nickel, and 24 for copper, for currents varying from 2 to 18 amperes. It was found that the polar lines were usually equally intense at the two electrodes, but that on some plates differences could be noted between their intensity at the two poles.

On summarizing the results, however, no certain connection could be established between their relative intensity and current-strength. It was also noted whether the width as well as the intensity of the lines near the poles varied with the current, as a change of potential gradient might alter the velocity of the luminous particle and thus affect any possible line-of-sight motion. It was found, however, that as a rule the lines were wider at the end where they were stronger, and this was probably due to mere photographic effect.

When some electrical measurements on the potential differences near the poles of metallic arcs were taken it was found that these discordant results might still be in part explained on the assumption that the polar lines are due to the strong potential gradients near the terminals. In the case of the two metals tried (iron and copper), the potential differences near the two poles were almost equal and varied but little and somewhat irregularly by varying the current; so that in this respect these two metallic arcs differ greatly from a carbon one.

The experimental method adopted was practically the same as that used by Mrs. Ayrton[1] and other workers for carbon arcs. A thin carbon rod carried by a special holder and sharpened to a long point was introduced in the metallic arc and the potential difference between it and either pole measured with a moving coil galvanometer (290 ohms resistance) with one megohm in series and a shunt of 20 ohms, the deflection on the scale being about 4 mm per volt. The iron and copper poles were 1.25 cm in diameter, the carbon electrode 4 mm, but owing to its sharp point the portion of it in the arc was never more than 1.5 mm in diameter. By having the exploring carbon first as close as possible to one pole, then to the other, and measuring the two potential differences in each case it was ascertained that the potential difference at the

[1] *The Electric Arc*, chap. vii.

center of the arc was of the order of about 2 volts, the main fall occurring near the poles. Hence, in all subsequent experiments, the exploring carbon was fixed at the center of the arc and the potential differences measured between it and the two poles. Owing to the unsteadiness of the iron arc and the tendency of the poles to melt, the measurements were very hard to take, especially at high currents and when the positive pole was below. The figures given below for iron have therefore to be taken as only very approximate. The readings for copper were taken with comparative ease, the copper arc being almost as steady as a carbon one, and the figures for copper ought to be correct within 10 per cent or less. The following tables are the summaries of the results for the two metals studied. The lengths and currents of the arcs were chosen so as to obtain more or less the same conditions at which most of the photographs of the spectra were taken.

IRON

Current in Amperes	Length in mm	Potential Differences in Volts at	
		+ Pole	− Pole
Positive Pole Above			
3.5	3.5	22.9	19.2
6.0	5.0	24.5	24.2
18.0	5.0	17.0	20.5
Positive Pole Below			
3	3.5	27.6	21.1
5	5	24.7	17.0
8	7	28.3	19.7
15	6	22.9	17.0

COPPER

Current in Amperes	Length in mm	Potential Differences in Volts at	
		+ Pole	− Pole
Positive Pole Above			
4	4	27.6	20.6
4	6	23.9	26.6
10	6	19.9	19.4
10	8.5	23.5	21.6
16	8.5	19.4	19.0
Positive Pole Below			
4	4	25.4	24.2
4	6	29.0	27.5
10	6	24.2	20.2
10	8.5	25.7	21.4
16	8.5	21.6	21.6

Although these experiments do not prove that the polar lines are due to steep potential gradients, they do not disprove that hypothesis. The practically equal intensity of the lines at the two poles, and the occasional slight irregular variation of intensity for changes of current and inversion of the polarity of the electrodes, are very similar to the behavior of the potential gradients in the

arc under the same conditions. This view is also in accord with the experiments of Crew[1] and of Nutting,[2] who consider potential gradient as the main cause for the production of spark lines in arc spectra. The latter found spark and polar lines very prominent in arc spectra at 4000 volts and 0.05 amperes.

The polar lines may of course be due to temperature; temperature and potential gradient in an electric arc being probably linked as they are in vacuum tube phenomena, numerous researches[3] in that direction having shown that they practically vary at the same rate. A point in favor of this view seems to be the fact remarked by Sir J. J. Thomson[4] that however the current be increased in a carbon arc the temperature of the crater remains constant. As stated before, the experiments of Mrs. Ayrton show that by increasing the current in the carbon arc the potential gradient near the cathode is more decreased than the one near the anode, the latter being little affected.

J. Hartmann's[5] chief objection to temperature as the cause of production of the magnesium polar line at λ 4481 studied by him and which he obtained much stronger in low-current than in high-current arcs was his assumption that the temperature in a large-current arc is higher than in a low-current arc. This view was deduced from the larger tendency of the electrodes to melt with a high current; but a larger mass of incandescent vapor at a lower temperature (which probably is the case in a high-current and low-potential arc) would certainly produce the same effect, especially on such low melting-point electrodes as magnesium. It is true that the work of Hale, Adams, and Gale[6] tends to show that a 30-ampere arc is hotter than a 2-ampere one; but in their experiments the difference of potential between the poles was kept approximately constant and further they dealt only with median arc

[1] *Astrophysical Journal*, **20**, 274, 1904.

[2] *Ibid*, **28**, 66, 1908.

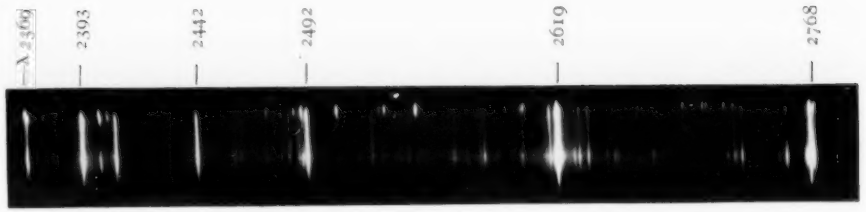
[3] Sir J. J. Thomson, *Electricity through Gases*, chaps. xvi and xvii.

[4] *Ibid.*, chap. xviii.

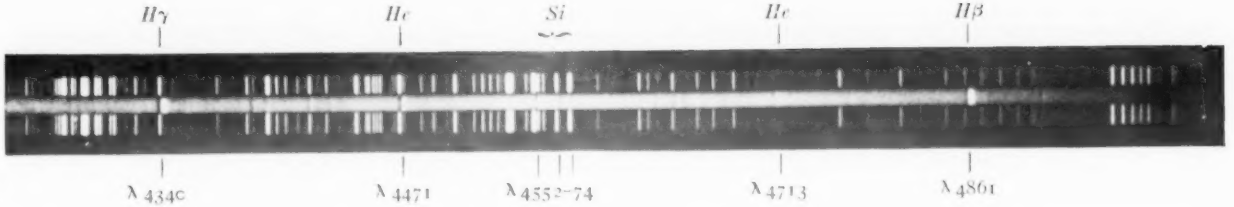
[5] *Astrophysical Journal*, **17**, 270, 1903.

[6] *Ibid.*, **24**, 185, 1906.

PLATE XIV



ROSSI: COPPER POLAR LINES APPEARING AT NEGATIVE ELECTRODE ONLY



FROST: SPECTRUM OF *P Cygni*
With Titanium Comparison Spectrum

lines and not polar lines; i.e., their considerations were probably applied to the central parts of the arc.

The only ground on which Duffield rejected temperature was that the lines were of the same intensity at the two poles which he assumed to be at different temperature. The present work, however, shows that the potential gradients are practically the same at the two electrodes and the temperature presumably the same.

The temperature hypothesis might also in part explain the fact that polar lines are more numerous and stronger in the ultra-violet than in any other region of the spectrum; for an increase of temperature of the emitting vapor (such as in passing from the center to the region near the poles of an arc) might be expected to be accompanied by an increase of the relative intensity of the more refrangible lines. This is in accord with some bolometric experiments by Pflüger[1] who has shown that in metallic sparks (where the vapor is at a high temperature) the maximum of energy is in the remote ultra-violet.

It would therefore appear from the above evidences that temperature or eventually potential gradient can afford a plausible explanation for the production of polar lines in arc spectra, the probable close relationship between these two causes rendering for the present impossible to ascertain which of them plays the most important part in the phenomenon.

I take this opportunity to thank Professor Rutherford for placing the necessary apparatus at my disposal.

PHYSICAL LABORATORIES
THE UNIVERSITY, MANCHESTER

[1] *Annalen der Physik*, **13**, 890, 1904.

ON THE SPECTRUM OF *P CYGNI*

By EDWIN B. FROST

This previously unrecorded star was discovered by Janson on August 18, 1600. It was observed by Kepler two years later when it was of the third magnitude, and it remained visible to the eye until 1621. Cassini found it to be of the third magnitude for a short time in 1655, and after another less-marked rise in 1665 it slowly declined in brightness. Since 1677 the light of the star has apparently been very nearly constant, at magnitude 5.0.

As is shown in Plate XIV, the striking features of the spectrum are the intense, broad, bright lines of hydrogen and helium and the relatively narrow adjacent dark lines which fringe the margins toward the violet and thus appear to have a very large displacement toward shorter wave-lengths.

This paper, the principal observational facts of which were communicated to a meeting of the Astronomical and Astrophysical Society[1] in 1905, is intended to show (1) that the spectrum has not varied appreciably in recent years; (2) that the displacements of the dark lines are spurious, being due merely to the fact that all but the edges of the dark lines are obscured on the photographic plate by the intense bright lines; and (3) that the radial velocity of the dark-line system is probably about −82 km per second, that of the bright-line system about −12 km. An explanation of the difference of 70 km in these two values is not obvious; and when spectrographic observations covering a much longer period of years have been made, this difference may perhaps be found variable. The velocity of the dark-line system, after correction for the solar motion, is about −65 km (approach), which is unusually large, but not exceptional for a steady radial velocity of a helium star.

The spectrograms have been taken with a dispersion of one prism, and are as given in the following list:

[1] *Publications of the Astronomical and Astrophysical Society of America*, 1, 244.

JOURNAL OF OBSERVATIONS

Number	Date	G.M.T.	Duration	Hour Angle	Quality	Observers
IB 348	1904 May 21	18^h23^m	60^m	E 3^h48^m	V.g.	F.B.S.
351	May 31	20 55	58	E 0 37	V.g.	F.S.
356	June 10	20 05	70	E 0 48	Too strong	F.S.
554	1905 June 23	20 20	60	W 0 25	Too strong	F.S.
583	Sept. 18	14 57	72	W 0 36	V.g.	F.S.
813	1906 July 23	19 36	66	W 1 30	V.g.	B.S.
842	Sept. 10	15 33	60	W 0 45	Weak	F.S.
1814	1908 Nov. 2	12 13	70	W 0 52	G.	L.
3049	1912 April 22	21 20	80	E 2 45	G.	G.S.
IA 11	1909 Sept. 27	15 18	155	W 1 28	Fair	F.L.S.

B. = Barrett; F. = Frost; G. = Gingrich; L. = Lee; S. = Sullivan.

The last spectrogram in the list, IA 11, was obtained with the instrument altered to include the red region, on a Cramer "Spectrum" plate. No. 3049 was secured after this manuscript had been written, on a Seed "L-Ortho" plate. It extends farther into green as well as into ultra-violet than most of the other plates of the series.

The principal lines observable on these plates are now given according to elements:

Hydrogen (with both bright and dark components): ϵ, λ 3970; δ, λ 4102; γ, λ 4340; β, λ 4861; α, λ 6563.

Helium (both bright and dark): $\lambda\lambda$ 3889, 3964, 4026, 4121, 4143, 4388, 4472, 4713, 4923, 5016, 5876 (D_3), 6678. Helium lines missing or very faint: $\lambda\lambda$ 4009 (dark only), 4024, 4169, 4438 (very faint), 5048 (dark component only visible).

Oxygen (both bright and dark): $\lambda\lambda$ 4349, 4351, 4367, 4591, 4649 (dark), 4661, 4676.

Nitrogen (bright and dark, unless otherwise indicated): $\lambda\lambda$ 3995, 4601, 4607, 4614 (d.), 4622, 4631, 4643.

Calcium (dark only): K, λ 3933.

Silicon (dark only): $\lambda\lambda$ 4553, 4567, 4574.

Unidentified lines: $\lambda\lambda$ 4002 (d.), 4004 (d.), 4252 (d.), 4419 (br.), 4570 (d.), 5055 (br.), 5043 (d.), 5123 (d.) and 5127 (br.), 5152 (d.) and 5155 (br.), 5189 (v. ft.), 5240 (br.), 5285 (d.), 5408 (d.), 5664 (d.) *N?*, 5676 (d.) *N?*

In the Harvard Revision (*Annals*, **50**) and in **56**, 183, the type

assigned to *P Cygni* is B4p—probably it is the only case where B4 occurs. In Harvard *Annals*, **56**, 171, we find it classed as "B1 with hydrogen lines bright." This latter assignment agrees better with the appearance of our spectra as indicated by the above list of lines.

The spectrum strongly resembles that of other novae at certain stages of their development, but with marked differences: the bright lines, and still more so the dark lines, are very much narrower in *P Cygni* than in novae; the bright lines are only slightly displaced and do not on these plates[1] show distinct components or maxima; they are not visible at H or at K; the bright band of novae at λ 4640 is not conspicuous beyond its fellows of oxygen and nitrogen in *P Cygni*. The dark lines, too, are single in *P Cygni* and their displacement, while large for an ordinary star, is small for a nova: numerous enhanced metallic lines are often seen in a nova, but few in *P Cygni*.

The evidence that the displacements of the absorption lines are spurious and merely due to the concealment of the greater part of the lines by the overlying bright line is most readily shown in the following tables, which indicate very different values of the velocity of approach for the different lines and different elements. The value of the displacement of the dark lines is given in Ångström

TABLE I

DISPLACEMENTS AND VELOCITIES FOR HYDROGEN LINES

PLATE	$H\delta$			$H\gamma$			$H\beta$		
	Dark		Bright	Dark		Bright	Dark		Bright
	Å	Km	Km	Å	Km	Km	Å	Km	Km
348	−2.39	−175	−14	−2.78	−192	−20	−3.52	−217	− 6
351	−2.25	−165	−11	−2.66	−184	−17	−3.54	−218	−10
356	−2.45	−179	− 4	−2.74	−189	− 9	−3.42	−211	− 8
554	−2.20	−161	− 7	−2.56	−177	+ 7	−3.88	−239	−10
583	.....	.....	....	−2.71	−187	− 5	.....	.....	....
813	.....	.....	....	−2.98	−205	−28	−3.75	−231	−15
842	.....	.....	....	−2.65	−183	−14	.....	.....	....
1814	−2.87	−210	− 4	−3.03	−209	−10	−3.66	−226	−21
3049	−2.12	−155	− 2	−2.46	−171	− 7	−3.47	−214	+ 5
Means	−2.38	−174	− 7	−2.73	−189	−11	−3.61	−223	− 9

Mean for 22 measures of bright H lines = −9.5 km.

[1] On Plate 583 there are suggestions of duplicity for bright $H\gamma$ and bright λ 4388.

units, to which are added the corresponding values as velocities, although it is not believed that this should be interpreted as due to velocity; but for the emission lines, the displacement is expressed only in km per second, as it would appear to be a genuine Doppler effect. Correction for the velocity of the earth has of course been made for each individual value.

Considering the hydrogen lines first, we note that in the mean the displacement of the dark component at $H\beta$ is -3.6 Å, as compared with -2.8 Å for $H\gamma$ and -2.4 Å for $H\delta$: if this were to be regarded as properly convertible into velocity, that derived for $H\beta$ would be greater by nearly 50 km than that for $H\delta$. This amount is obviously much in excess of even the large accidental errors unavoidable in the measurement of such broad lines; and at once negatives the possibility that these are Doppler effects.

TABLE II

DISPLACEMENTS AND VELOCITIES FOR HELIUM LINES

PLATE	λ 4388.100			λ 4471.676			λ 4713.308		
	Dark		Bright	Dark		Bright	Dark		Bright
	Å	Km	Km	Å	Km	Km	Å	Km	Km
348	−1.90	−130	−34	−2.46	−165	−23	−2.22	−141	....
351	−1.76	−120	−14	−2.49	−167	−18	−2.09	−133	−17
356	−1.86	−127	....	−2.53	−170	0:	−2.53	−161	....
554	−2.02	−138	....	−2.41	−162	−19	−2.22	−141	−11
583	−1.68	−115	+ 4:	−2.49	−167	− 8	.....	.....	....
813	−2.01	−137	− 6	−2.53	−170	−11	.....	.....	....
842	−1.79	−122	....	−2.44	−164	−12	.....	.....	....
1814	−1.61	−110	−24	−2.52	−169	−24	−2.34	−149	−24
3049	−1.98	−135	+ 2:	−2.27	−152	−12	−2.34	−149	−28
Means	−1.85	−126	−12	−2.46	−165	−14	−2.29	−146	−20

Mean for the 19 measures of bright *He* lines = −14.7 km.

Per contra, the displacements of the centers of the bright lines are in excellent accordance, with a mean velocity of 10 km of approach. This is a very reasonable value of the velocity of a helium star; it is confirmed by the velocity derived from the bright components of the three principal helium lines, which will be seen from Table II to be −15 km (this small difference of 5 km has no significance in settings on the centers of such very broad lines). On one plate the displacements of the stronger lines of

oxygen and nitrogen in the region λ 4600–4700 were measured. The values of the velocity for the bright components are again entirely consistent with those above. We therefore conclude that the measures upon the centers of the bright lines yield the radial velocity of the body or envelope from which they originate, except as possibly modified by pressure.

Reverting to the dark components, we note in Table II that there is similarly a consistent difference in displacement among themselves for the helium lines, but without any apparent relation to the wave-length. The mean of all velocities of the dark components of the three hydrogen lines would be more than 50 km greater than the similar mean for the three helium lines, a condition wholly inconsistent with any interpretation of their displacements as a Doppler effect.

TABLE III

VELOCITIES FOR SILICON LINES (DARK ONLY)

Plate	λ 4552.636	λ 4567.897	λ 4574.791	Mean
	Km	Km	Km	Km
348	− 74	−91	−85	−83
351	− 82	−75	−72	−76
356	− 74	−86	−66:	−75
554	− 97	−67	−71	−78
583	− 82	−98	−82	−87
813	− 85	−76	−78	−80
842	−106	−87	−95	−96
1814	− 92	−86	−72:	−83
3049	− 82	−84	−81	−82
Means	− 86	−83	−78	82

This is still more strikingly brought out when we pass to the silicon lines, which are dark, without visible emission components on these plates.[1] Table III shows the evidence (which was noted eight years ago, as the first of the plates were measured) that we have here a very different radial velocity, practically identical[2]

[1] An occasional suspicion of a bright component to *Si* 4553 is indicated in the notes: No. 583: "Probably no bright"; No. 3049: Settings were made on "Is it a bright fringe?" It yielded a value of +8 km. In many cases it was recorded that no bright fringes were visible.

[2] It would be more appropriate in measurements on such stars as novae, and in general on those having very broad lines, to employ for velocity a unit of 10 kilometers; that unit, the "myriameter," has been so little used, however, that its employment in special cases might lead to confusion.

for the three lines and apparently constant during the eight years covered by the plates, at about −82 km. As we see no bright components which might be masking all but the more refrangible positions of the dark lines, we are not justified in making any other assumption than that we obtain from the three silicon lines the true velocity in the line of sight of the body or envelope responsible for the absorption lines.

It remains to see what would be the true breadth of the dark lines, on this assumption that the actual velocity for the dark components is −82 km per second, and that their apparently narrow character is due to their being for the most part covered up by the broad overlying bright components. On the spectrograms best

TABLE IV

WIDTHS IN ÅNGSTRÖMS OF CERTAIN LINES

PLATE	*Hδ*		*Hγ*		*Hβ*		*He* λ 4472	
	Bright	Dark	Bright	Dark	Bright	Dark	Bright	Dark
348	...	...	3.0	...	3.9	...	...	...
351	2.0	1.6	3.2	1.5	4.2	2.0	2.6	1.6
554	2.2	1.4	3.5	0.9	3.8	2.8	2.6	1.3
813	...	...	2.9	2.0	4.0	2.4	2.4	1.8
842	...	...	2.8	1.9	...	...	2.0	1.9
1814	2.0	1.0	2.9	1.0	4.4	2.0	1.5	1.5
3049	2.3	1.9	2.8	1.7	5.2	1.6	1.9	1.9
Means	2.1	1.5	3.0	1.5	4.3	2.0	2.2	1.6

suited for this purpose, I made settings on the edges of both bright and dark components, whence were derived the widths of the lines, as given in Table IV. Taking the relative difference in velocity for the centers of the bright lines and the concealed centers of the dark lines to be 70 km, we examine the data to find whether the margins toward red of the dark lines ought to project beyond the margins of the bright components. It can readily be shown that they should thus project only when the width of the visible portion of the dark component is greater than twice the relative displacement. The displacement corresponding to 70 km is as follows for the lines concerned: *Hδ*, 0.96 Å; *Hγ*, 1.01 Å; *Hβ*, 1.13 Å; *He*, λ 4472, 1.04 Å. Hence there should be second dark components

on the red-ward margins of the bright lines only when the visible width of the dark components exceed twice these values, or from 1.92 Å for $H\delta$ to 2.26 Å for $H\beta$. It will be seen from the table that the mean widths of the dark lines are well under this limit. There is but one individual exception, for $H\beta$ on No. 813, and here the setting on the vague edges of the bright line is doubtless at fault. Careful examination of the spectrograms does not show any dark margins on the edges toward red, so that this evidence, although in a sense negative, tends to confirm the interpretation we have given.

It will be seen from Table IV that the widths for the bright hydrogen lines, δ, γ, and β, are in about the ratio 2:3:4. Hence it is to be expected that the broadest lines will give the largest spurious displacement to their dark components, as was shown to be the case in Table I. The bright lines are much less broad than is usually the case for an active nova.

If we regard the spectrum of *P Cygni* to be due to a single body having a radial velocity of approach of 82 km, then the bright components are displaced toward the red by the equivalent of 82–13 km, or 1.0 Å at $H\gamma$, 1.1 Å at $H\beta$. We have no adequate data as to the quantitative effect of pressure upon the displacement of lines of permanent gases like hydrogen and helium; but if of the order of the shifts for metallic lines, this would imply a pressure of over 200 atmospheres, effective in the portion of the star emitting the bright lines, but not in the reversing layer. While this seems highly improbable, the phenomena of temporary stars are generally so improbable that they would a priori be regarded as impossible.

My results are in excellent agreement with those obtained by Belopolsky[1] from spectrograms taken on September 21 and 22, 1899. The special purpose of his article was to call attention to the identity of numerous lines (chiefly between λ 4601 and λ 4651) with those of air lines (*N* and *O*) in his comparison spectrum, which had not been previously established. Belopolsky gives substantially the same displacements for the hydrogen lines β and γ that I have tabulated above, which is additional evidence of the absence of any considerable change in the spectrum in nearly 13 years. He attributes the difference in displacement for the dark $H\beta$ and $H\gamma$ to

[1] *Astrophysical Journal*, **10**, 319, 1899; *Astronomische Nachrichten*, **151**, 37, 1899.

photographic irradiation, if I correctly interpret his words: "This is certainly to be explained by silver precipitation of the bright lines overlying the dark lines at their edges, so that the observer makes his settings on the edge of the bright line, and not on the dark line." Photographic irradiation evidently does complicate the measurements on such spectra, tending to narrow the visible dark components, besides giving an undue width to the strong bright lines.

It is unfortunate that only one of our spectrograms (that last secured) is strong enough at K to give us information as to that interesting line. It appears to have no bright component, being a quite narrow dark line. It yielded a velocity of 0 km, thus differing widely from the dark silicon lines. Such behavior of the K line is found so frequently in spectra of type B that it is hardly abnormal, although as yet unexplained.

Paul W. Merrill has recently[1] published a note on the spectrum of *P Cygni*, from which it appears that bright components of the silicon lines are visible on the three-prism spectrograms taken at Mt. Hamilton, and that these bright lines have a displacement toward the red of 0.26 Å as compared with the bright lines of *H* and *He*. I am somewhat surprised that these bright *Si* components should not be more conspicuous on our single-prism plates than on these three-prism plates, but it is evidently not the case. The effect of invisible bright components on my measures of these dark lines would be to make the negative displacements too great, so that the velocity of −82 km inferred from these lines might be too large. Mr. Merrill's velocities for the bright hydrogen and helium lines are practically in agreement with those given here.

My interest in this spectrum has been largely due to the hope that some of the complications in the spectrum of *β Lyrae* might be explained if we assigned to one of the components a character like that of *P Cygni*. There are many points of similarity in the spectra of the two stars, and if an oscillating system of lines, due to the orbital revolution of a second body, were superposed upon the spectrum of *P Cygni*, it would reproduce some of the interesting features of *β Lyrae*.

YERKES OBSERVATORY
April 19

[1] *Lick Bulletin No. 201.*

Reviews

Transactions of the International Union for Co-operation in Solar Research, Vol. III (Fourth Conference). Manchester and London: Sherratt & Hughes; New York: Longmans Green & Co., 1911. 8vo, pp. 231. $2.50.

This volume follows the style of the two which have preceded it, except that the duplication of the records of the sessions in French and German is avoided, English being used as the language of the country in which the meeting was held. A very accurate stenographic report of the interesting meetings on Mount Wilson occupies the first 133 pages. The proof sheets of the report were submitted to the persons concerned and hence it may be regarded as authentic in every way. The attendance at the four sessions was large, and the discussions had numerous participants, adding to the value and interest of the record. Part IV contains in four pages the text of all the resolutions adopted by the Union at Mt. Wilson. Part VI (pp. 139–200) gives the reports of the committees, together with papers communicated to the Union for this meeting. These reports include those on standard wave-lengths, on the measurement of solar radiation, on work with the spectroheliograph, on sun-spot spectra, on eclipse observations; together with individual papers by M. Deslandres: "Sur les spectrohéliographes de grande dispersion," "Isolement des couches supérieures de l'atmosphère solaire," "Sur le spectro-enregistreur des vitesses radiales du soleil"; and by M. Perot: "Sur la signification des mésures de vitesse de rotation par la méthode spectroscopique," and "Sur la rotation du soleil."

The volume closes with the two evening addresses delivered at the conference, by Mr. C. G. Abbot on "The Solar Constant," and by Professor Kapteyn "On the Systematic Proper Motion of the *Orion* Stars."

Those who were fortunate enough to be able to attend this memorable conference have doubtless already secured copies of this volume; those who were not so fortunate can supply the deficiency to some extent by securing copies for themselves and for the libraries in which they are interested.

F.

The Progress of Physics during 33 Years (1875–1908). By ARTHUR SCHUSTER. Cambridge: The University Press, 1911. 8vo, pp. 164, with frontispiece portrait of J. CLERK MAXWELL. 3*s*. 6*d*. net.

This slender volume comprises four lectures delivered to the University of Calcutta in March 1908. The third of a century included by the lecturer was that which had elapsed between his first and his second visits to India. The author's intention was to record the changes in the point of view of physical science rather than to give a historical account of the discoveries made during the period; and he warns his hearers that the account will be fragmentary, and to a considerable extent reminiscent of scientific matters with which the author has had personal relations. This personal touch, with recollections of Maxwell, and the early workers at the Cavendish laboratory, of Helmholtz and the men gathered about him at Berlin, gives a special interest to the lectures. The cosmopolitan character of the author's education and experience contributes to the catholic view displayed throughout the book.

Titles are not assigned to the separate lectures, which overlap to some extent, and the whole treatment is delightfully informal and covers a large number of topics, as may be seen from the following excerpts.

From Lecture I: State of Physics in 1875. Maxwell's theory of electricity. Kirchhoff's laboratory. The two laboratories of Berlin. Laboratory instruction at Manchester. Spectrum analysis. The radiometer. Theory of vortex atom.

From Lecture II: Verification of electromagnetic theory by Hertz. Wireless telegraphy. Early experiments in electric discharge through gases. Kathode rays. Ionization of gases. Measurement of atomic charge.

From Lecture III: Roentgen's discovery. Discovery of emanations. Decay of the atom. The Michelson-Morley experiment. Principle of relativity. The Zeeman effect. Contrast between old and modern school of physics.

From Lecture IV: Terrestrial magnetism. Existence of potential. Separation of internal and external causes. Magnetic storms. Solar influences. Atmospheric electricity. Cause of thunderstorms. Age of the earth. Gravitation.

Enough has been said to show that every physicist, and those having interests in related branches, will greatly enjoy as well as profit by the reading of this book.

F.

THE COLLECTED SCIENTIFIC WORKS OF SIR WILLIAM HERSCHEL

We have pleasure in drawing attention, at the request of the Royal Society and the Royal Astronomical Society of London, to the publication at their expense, in a limited edition, of *The Scientific Papers of Sir William Herschel*, in two volumes, royal quarto, in boards, Vol. I, pp. i–cxx, 1–597; Vol. II, pp. i–viii, 1–718, with 3 portraits and other plates. The agents for sale are Dulau & Co., 37 Soho Square, London, W., who will forward the work direct at the price of £2, 10*s* net. The following description is reproduced from the Preface:

Soon after the death of Sir William Herschel in 1822, his distinguished son, Sir John F. W. Herschel, F.R.S., formed the plan of republishing his father's papers; but he found on inquiry that no publisher would be willing to undertake the risk of so extensive a work. He therefore resigned the idea, considering that he might contribute more effectually toward a monument to his father's memory by devoting himself to extending and carrying out, with his own instruments and after his own manner, his father's processes of observation. A German translation was commenced by Professor J. W. Pfaff of Erlangen, but only the first volume was published (*W. Herschel Sämmtliche Schriften*. Erster Band: "Ueber den Bau des Himmels." Dresden und Leipzig, 1826, 8°).

The papers of W. Herschel are scattered over about forty volumes of the *Philosophical Transactions*, and they have become difficult of access to many to whom their study is of importance. A useful summary of their contents was published by Professors Hastings and Holden in the *Smithsonian Report* for 1880, but a collected edition of the papers has always been considered a *desideratum* in astronomical literature, and from time to time it has been strongly urged that a complete reprint should be made available.

Early in the year 1910 the matter was taken in hand, and a committee was appointed by the Royal Society and the Royal Astronomical Society to prepare an edition of William Herschel's works at the joint expense of the two societies. It consisted of Sir William Huggins (who was prominent in promoting the work, but was only able to preside over two meetings of the committee before his death), Sir Joseph Larmor and Professor R. A. Sampson, representing the Royal Society, and Sir David Gill, Mr. J. A. Hardcastle, and Professor H. H. Turner, representing the Royal Astronomical Society. Soon afterward Dr. J. L. E. Dreyer and Major E. H. Hills, and finally Mr. F. W. Dyson, Astronomer Royal, were added to the committee.

It seemed desirable to reprint all Herschel's published papers exactly as they had been issued by him, without omissions or alterations—except that actual errors of observation, or identification of the observed objects, should be pointed out. Some errors of this kind in the observations of Double Stars had been found, chiefly by the late Mr. H. Sadler, from an examination

of the MS sheets belonging to the Royal Astronomical Society; and these have now been checked where necessary by reference to the original observing journal. But it appeared to be specially important to take this opportunity to make a revision of the three catalogues of nebulae in order to clear up many difficulties in reconciling Herschel's results with those of later observers. This has been done by an examination of the original "sweeps," which, together with Caroline Herschel's *Zone Catalogue* and the observations of the objects in Messier's catalogue, were lent for this purpose by the Royal Society. It is hoped that this revision has resulted in improving the accuracy of the three catalogues; but at the same time it should be stated that the revision has furnished additional proofs of the very great care with which the observations were both made and reduced.

The reprint has been made complete as regards the published scientific work, though this has involved the insertion in Vol. II of three papers on Newton's colored rings, which have not more than a personal interest (see Introduction, pp. lvii–lviii).

The committee have been under great obligations to Sir William J. Herschel, Bart., who generously placed at their disposal his grandfather's letters, his observing journal, the record of the polishing of mirrors, and also autobiographical memoranda and unpublished papers. Everything of importance that could be extracted from these valuable materials, and brought within reasonable limits of space, has been given in the Introduction to the present volumes.

Many incidents of Herschel's career have thus been presented in a new light, especially as regards his early life; while the papers read before the Bath Philosophical Society form an interesting record of his early modes of thought and of the versatility of his mind, in addition to affording an illustration of the remarkable activity of genuine physical speculation in England, at a time when formal mathematical analysis was but slightly cultivated.

The joint committee aforesaid of the Royal Society and the Royal Astronomical Society are responsible for the general plan of the work. But they desire to record their obligation, and that of the astronomers who will use the reprint, to one of their number, Dr. J. L. E. Dreyer, who very generously undertook both the collation of the manuscripts and the preparation of the introductory memoir.

Descriptive Meteorology. By WILLIS L. MOORE. New York and London: D. Appleton & Co., 1910. 8vo, pp. 344, with 81 text illustrations and 45 charts. $3.00 net.

In preparing this valuable work the Chief of the United States Weather Bureau has had many advantages, such as long experience in practical meteorology, association with many experts in the past and

present history of this branch of science in America, continuous access to the remarkably complete library of our national Weather Bureau, and direct consultation with the leading men of its staff on the subjects in which they are authorities. Under the last head acknowledgments are made to Professors Abbe, Bigelow, Kimball, Henry, Talman, Cox, and Humphreys.

The book is both theoretical and practical, and is intended to lead up to the art of forecasting the weather, for which the North American continent offers many natural advantages. One purpose of the work was to provide for the needs of the young men entering the United States Weather service, to whom some of the great treatises in foreign languages might not be available.

The subject is treated in fifteen chapters as follows: the atmospheres of the earth and of the planets; atmospheric air; micro-organisms and dust-motes of the air; physical conditions of the sun and its relation to the earth's atmosphere; heat, light, and temperature; thermometry; distribution of insolation, and the resulting temperatures of the atmosphere, the land, and the water; the isothermal layer; atmospheric pressure and circulation; the winds of the globe; the clouds; precipitation; forecasting the weather and storms; optical phenomena in meteorology; climate.

Among the features in which a departure is made from the mode of presentation in most other works on meteorology we may mention particularly: the treatment of the astronomical climate, which a smooth spherical earth would have without an atmosphere, from which the reader is led to the modifications produced by the atmosphere and the earth's surface; the diagrams of the relative proportions at different elevations of the constituents of this atmosphere; the discussion of the actually observed motions of the air at various elevations in cyclones and anticyclones; of the vertical distribution of temperature under different conditions of the weather; of the isothermal layer. All these are matters in which the information lately gained from kites and sounding balloons is made available.

The chapter on forecasting (in America) is thoroughly practical. It is finally illustrated by many appropriate charts at the end of the volume. The numerous illustrations throughout the book are largely new and excellent. A brief bibliography at the end of each chapter gives the principal references for the topic under discussion.

The author has avoided the temptation of going too much into statistics; in some respects more such information might have been desirable.

The book is in every respect handsomely gotten up and should prove of wide service in astronomical libraries and in the hands of many besides those for whom it was primarily intended.

F.

The Great Star Map. By H. H. TURNER. London: John Murray, 1912; New York: E. P. Dutton & Co. Crown 8vo, pp. 159, with frontispiece. Price: in London *2s. 6d.;* in New York, $1.00 net.

As stated on the title-page, this is "a brief general account of the international project known as the Astrographic Chart." The author has to an unusual degree the art of describing things simply and interestingly, both for the general reader and for those technically familiar with a subject. The four chapters are entitled: I, "Introduction"; II, "Star Counting"; III, "Star Positions"; IV, "Some Incidents of the Work." Twelve "notes" occupy the last twenty pages and give details which would chiefly interest astronomers.

The marked difference in price of the work in England and America will lead to renewed contemplation of the utility of a duty on books printed in England.

F.

Star Lore of All Ages. By WILLIAM TYLER OLCOTT. New York: Putnam, 1911. Pp. 453 with 50 text illustrations and 64 full-page engravings. $3.50 net.

The title-page of this handsome work describes it as "A Collection of Myths, Legends and Facts concerning the Constellations of the Northern Hemisphere." Emphasis is particularly placed upon the myths and legends, and less upon the facts; where the facts are recorded, the author has depended largely upon second-hand information, and his assignment of the authority upon whom a fact depends is thus often incorrect. Published data are, perhaps naturally, accepted by the author at their face value, without serious question of their reliability. Thus of the Great Nebula in *Andromeda* we read: "Recent and more reliable calculations of its distance give it a light-journey of about nineteen years."

It is not, however, for its value as a record of astronomical progress that this work will properly find a place in the library of the teacher and amateur. The mythological associations with the stars and constellations are many, and are not to be found in the regular astronomical

treatises, when required for lecture purposes or otherwise. The author shows familiarity with these phases of his subject and gives evidence of wide reading and study. He acknowledges his indebtedness to R. H. Allen's *Star Names and Their Meanings*. The numerous full-page illustrations are chiefly from classical paintings and statuary, are well chosen and finely reproduced. The work should serve a very useful purpose.

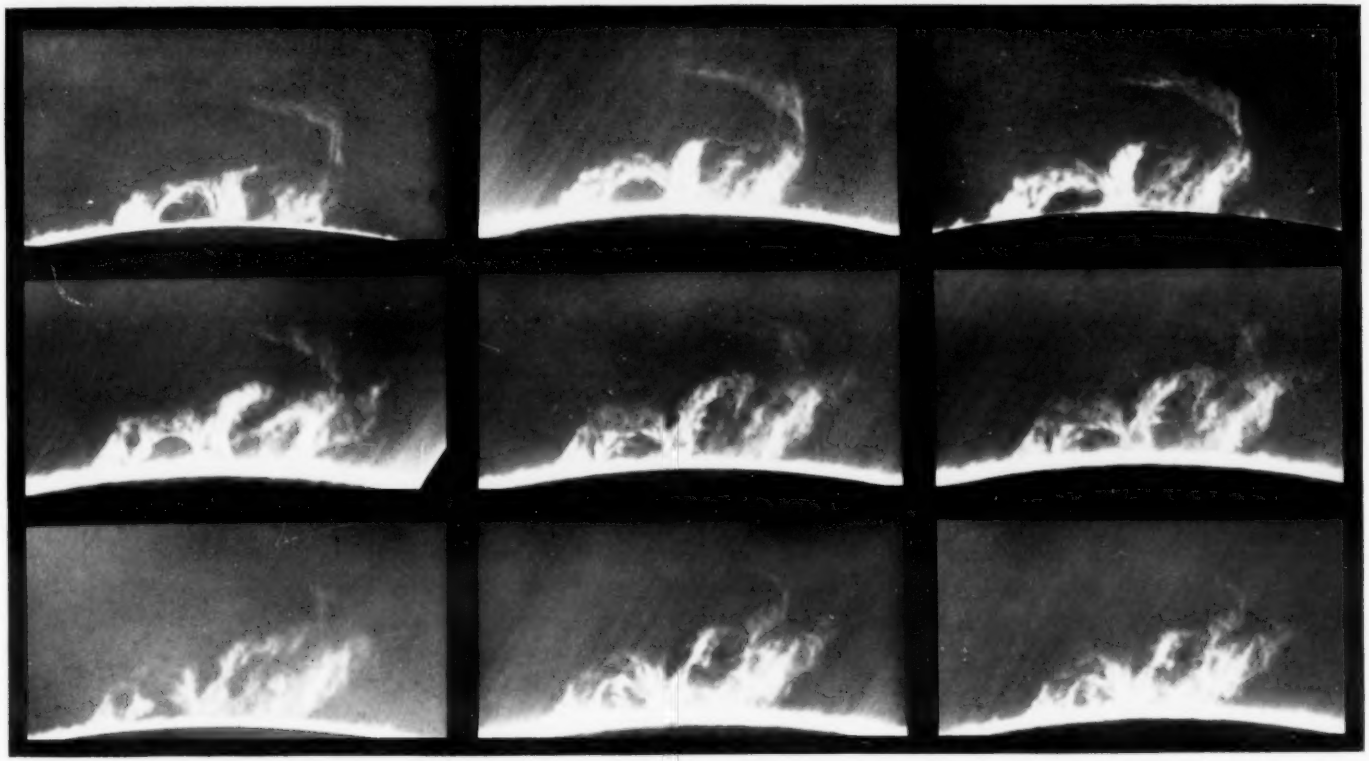
F.

Tables of Physical and Chemical Constants and Some Mathematical Functions. By G. W. C. KAYE and T. H. LABY. London and New York: Longmans, Green & Co., 1911. Royal 8vo, pp. 153. $1.50.

This latest table of constants differs from others in its compactness and the amount of data from the most recent fields of investigation, such as ionization, radioactivity, etc. Undue abbreviation is not practiced, the type is clear, the size of the page is convenient, and the flexible cover adds to the handiness of the book. The tables are not numbered, but are very numerous, and the range covered in small compass is surprising. We predict for the book a career of usefulness which will call for new editions.

F.

PLATE XV

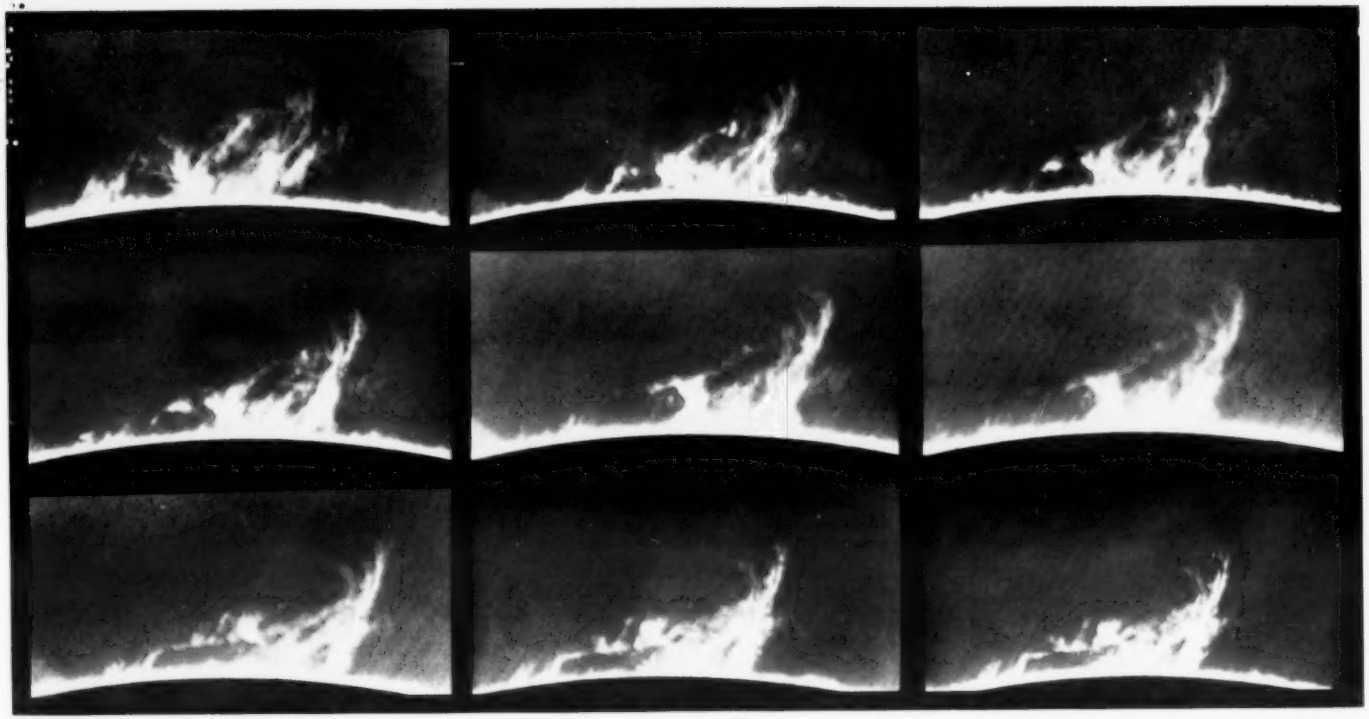


CALCIUM SPECTROHELIOGRAMS OF SOLAR PROMINENCES ON JUNE 19, 1911

Scale: Sun's Diameter = 260 mm

$2^h\ 18^m.2$ G.M.T.	$3^h\ 4^m.3$	$3^h\ 12^m.5$
4 1.5	4 33.8	4 36.9
5 10.3	5 32.9	5 34.0

PLATE XVI

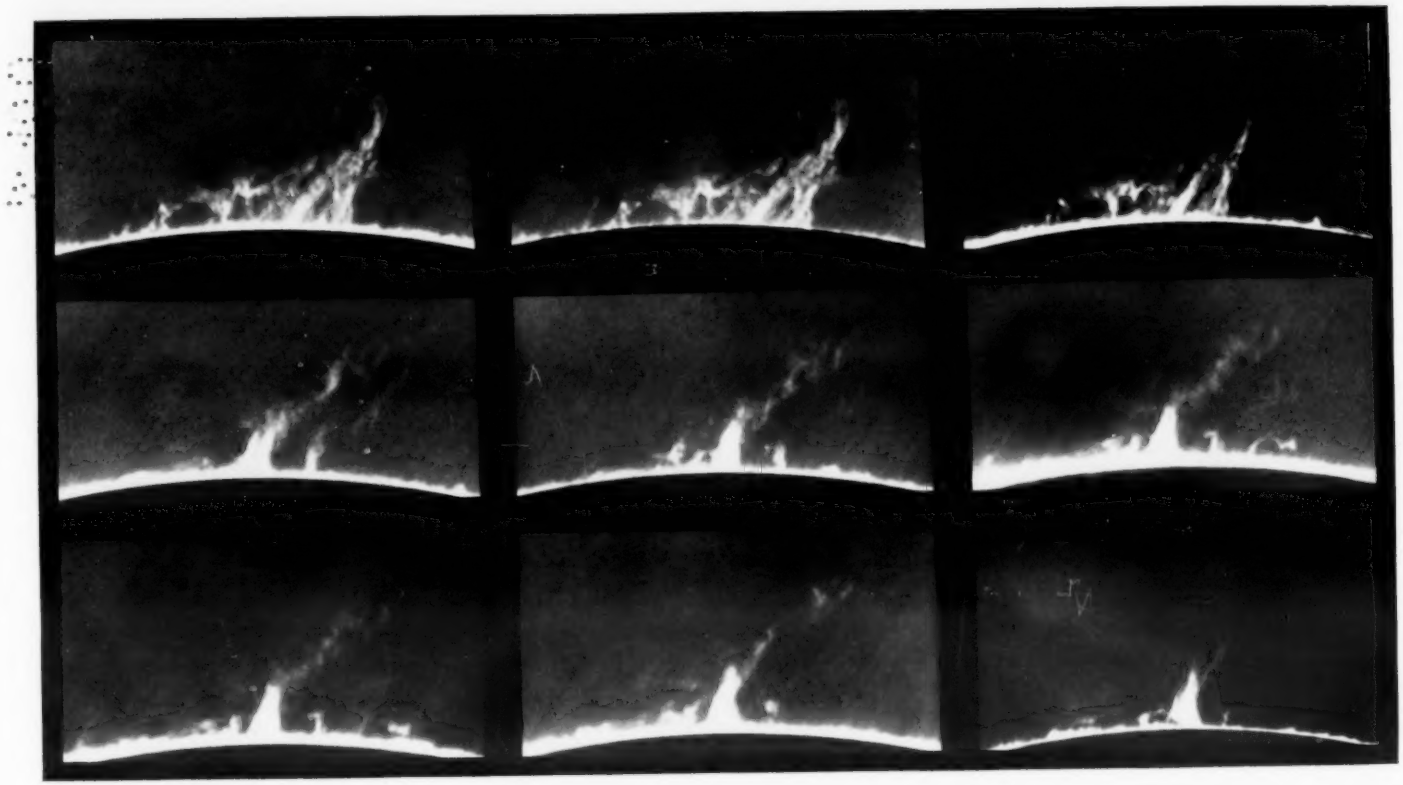


Calcium Spectrohelioграms of Solar Prominences on June 19, 1911

Scale: Sun's Diameter = 260 mm

$5^h\ 58^m.3$ G.M.T.	$7^h\ 39^m.5$	$7^h\ 50^m.3$
7 53.3	8 17.5	8 19.4
8 58.0	9 8.3	9 10.0

PLATE XVII



CALCIUM SPECTROHELIOGRAMS OF SOLAR PROMINENCES ON JUNE 19 AND 20, 1911

Scale: Sun's Diameter = 260 mm

June 19 $9^h\ 45^m.5$ G.M.T.	$9^h\ 47^m.5$	$9^h\ 55^m.3$
June 20 2 3.3	2 58.6	3 9.5
June 20 3 12.1	3 54.1	4 58.1